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Neolithic agriculture on the European western frontier: the boom and bust of early farming in Ireland

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ABSTRACT

A multi-disciplinary study assessing the evidence for agriculture in Neolithic Ireland is presented, examining the timing, extent and nature of settlement and farming. Bayesian analyses of palaeoenvironmental and archaeological ^{14}C data have allowed us to re-examine evidential strands within a strong chronological framework. While the nature and timing of the very beginning of the Neolithic in Ireland is still debated, our results – based on new Bayesian chronologies of plant macro-remains – are consistent with a rapid and abrupt transition to agriculture from c. 3750 cal BC, though there are hints of earlier Neolithic presence at a number of sites. We have emphatically confirmed the start of extensive Neolithic settlement in Ireland with the existence of a distinct 'house horizon', dating to *3720–3620 cal BC*, lasting for up to a century. Cereals were being consumed at many sites during this period, with emmer wheat dominant, but also barley (naked and hulled), as well as occasional evidence for einkorn wheat, naked wheat and flax. The earliest farmers in Ireland, like farmers elsewhere across NW Europe, were not engaged in shifting cultivation, but practised longer-term fixed-plot agriculture. The association between early agriculture and the Elm Decline seen in many pollen diagrams shows that this latter event was not synchronous across all sites investigated, starting earlier in the north compared with the west, but that there is a strong coincidence with early agriculture at many sites. After this early boom, there are changes in the nature of settlement records; aside from passage tombs, the evidence for activity between 3400 and 3100 cal BC is limited. From 3400 cal BC, we see a decrease in the frequency of cereal evidence and an increase in some wild resources (e.g. fruits, but not nuts, in the records), alongside evidence for re-afforestation in pollen diagrams (3500–3000 cal BC). Changes occur at a time of worsening climatic conditions, as shown in Irish bog oak and reconstructed bog surface wetness records, although the links between the various records, and assessment of causes and effects, will require further investigation and may prove complex. This period seems to have been one of environmental, landscape, settlement and economic change. The later 4th millennium BC emerges as a period that would benefit from focused research attention, particularly as the observed changes in Ireland seem to have parallels in Britain and further afield.

1. Introduction

How did farming practices evolve and develop over the course of the Neolithic and what were their associated landscape contexts and impacts? How did the nature of settlement develop? What was the environmental and climatic backdrop to this period? These are some of the questions we set out to address with reference to Neolithic Ireland. We define the 'Neolithic' in Ireland

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as a subsistence economy dominated by domestic plants and animals (Zvelebil and Rowley-Conwy, 1984), alongside the presence of pottery, polished stone and flint axes, rectangular structures and monumental architecture.

The origins and spread of Neolithic agriculture in Europe, and its associated societal impacts continue to remain a major focus in world archaeology. This period is one of the most important transitions in human history and is defined by profound cultural, socioeconomic and technological changes that initiated significant effects on the wider environment and its associated ecosystems and biota, leading to major anthropogenic changes in land cover and use (Kaplan et al. 2010). On the western fringes of Europe, Ireland is often absent from discussions of Neolithic archaeology, except as a subsidiary to British research (but see Cooney et al. 2011 for recent advances). Distinct differences in the Neolithic archaeology of Britain and Ireland have been demonstrated (cf. Cooney, 2000; Bradley, 2007), although they are, clearly, not unconnected. Some British researchers have emphasized continuity in both settlement and economy from the Mesolithic to the Neolithic (Thomas, 1999, 2004, 2008; cf. Hodder, 1990), whilst others have advocated a rapid shift towards domesticated resources coincident with the abrupt appearance of distinct Neolithic material culture and practices (Richards et al. 2003; Rowley-Conwy, 2004, 2011; Jones and Rowley-Conwy, 2007), perhaps associated with 'colonising farmers' (*cf.* Childe, 1936; Collard et al. 2010). Crop husbandry practices in Early Neolithic Britain suggest the permanent and intensive nature of cultivation (Bogaard and Jones, 2007), parallelling results from the Continent (Bogaard, 2004; Kreuz et al. 2005). The evidence emerging from many parts of Europe suggests a 'settled' Neolithic, but it has been unclear where Ireland fits into this wider European context.

While there has been much debate about the mechanisms associated with the transition to early agriculture (e.g. Thomas, 1999, 2008; Sheridan, 2004, 2007), there has been less emphasis on what happened after this event. What were the situations in which crops and animals were consumed and deposited, and did these change over the course of the Neolithic? In Ireland, we know that the main crops were emmer, einkorn wheat and barley (Monk, 2000), but we know little about their relative importance, production methods and intensity of cultivation, and variation in crops through space and time.

The Irish pollen record is abundant and regionally diverse, providing an opportunity to examine the wider landscape context of this period. Despite a long tradition of Irish palaeoecology, these records, as elsewhere, have seldom been explored in tandem with plant and animal economic data, an essential linkage if we are to fully understand the nature of Neolithic farming. Parker-Pearson (2003, 1) has rightly highlighted that environmental archaeologists have been reluctant to step out of their specialisms to provide over-arching narratives that attempt to marry a range of proxy data from a diverse range of environmental sub-disciplines. The integration of these records with other aspects of the archaeological record provides an opportunity to investigate the creation, appearance and local perceptions of Neolithic landscapes. Precise chronological control is key to integrating these records; recent developments using Bayesian approaches offer potential for such lines of enquiry at human time-scales (e.g. Buck et al. 1994, 1996; Bronk Ramsey, 2009a,b). These records allow us to focus on the *pathways* of early farming during this period, rather than on the vexed question of the origins and introduction of agriculture and the role of migration versus indigenous acculturation. Whilst of central importance to the Neolithic, this focus on origins has drawn attention away from the centuries following the initial appearance of farming and the changing nature of the economic, archaeological and landscape record, as groups settled into new subsistence economies.

The aim of this contribution is to discuss the findings of a major research programme funded by the Heritage Council, Republic of Ireland (2008–2010). The project was concerned with examining the extent and nature of Neolithic farming in Ireland by drawing upon unpublished and published data from the private, state and academic sectors. A particular focus was the collection of data emanating from the 'grey' and unpublished literature associated with archaeobotanical and palaeoecological data, within the context of a ^{14}C dating programme and Bayesian re-evaluation of existing chronological data from archaeological and palaeoecological sites. Regrettably, there is a limited faunal record for this period, although we have considered these data where possible. We have examined the relationships between plant economies, environment, landscape and settlement against their wider palaeoenvironmental (including climatic) backdrop.

1.1. Existing state of knowledge

Ireland has produced the earliest evidence for the presence of reportedly domesticated animals for the islands of Ireland and Britain, from Ferriter's Cove, Co. Kerry (Fig. 1), where cattle bone is directly dated to 4450–4270 cal BC (5510 ± 70 BP, OxA-3869) (Woodman et al. 1999). Its presence suggests the possibility of an

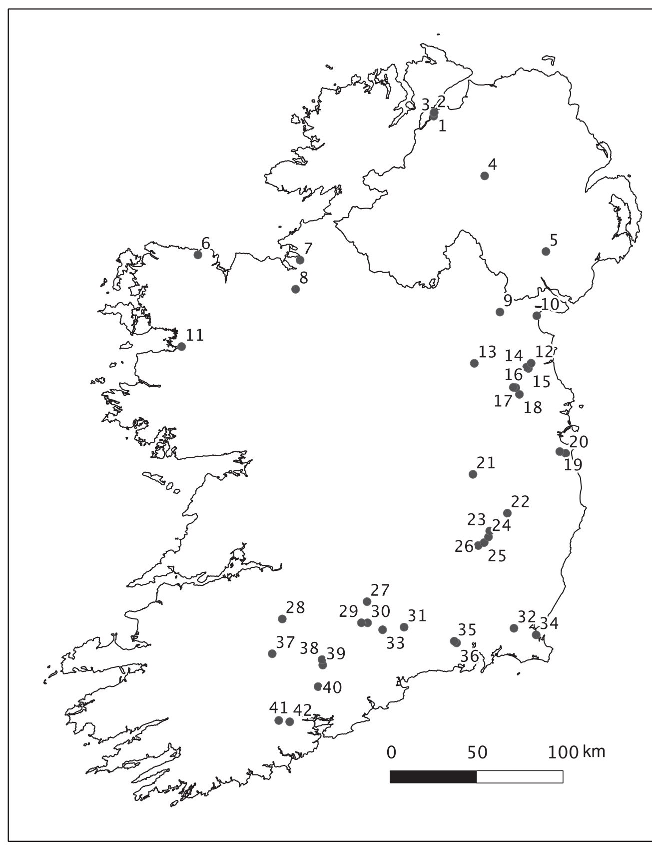

Fig. 1. Location map of archaeological sites mentioned in the text; palaeoecological sites are shown in Fig. 15. Key to sites: 1. Enagh, 2. Gransha, 3. Caw, 4. Ballynagilly, 5. Ballintaggart, 6. Ballyglass, 7. Magheraboy, 8. Rathdooney Beg, 9. Monanny, 10. Haggardstown, 11. Gortaroe, 12. Townleyhall, 13. Drumbaragh, 14. Knowth, 15. Newgrange, 16. Castletown Tara, 17. Lismullin, 18. Clowanstown, 19. Kilgobbin, 20. Carrickmines Great, 21. Cherryville, 22. Pinnacle, Coolinarrig Upper and Tuckmill Hill, 23. Russellstown, 24. Busherstown, 25. Tinryland, 26. Ballybannon, 27. Lough Feedora, 28. Tankardstown South, 29. Caherabbey Upper, 30. Suttonrath, 31. Kilsheelan, Poulakerry and Cloghcarigeen East, 32. Harristown Big, 33. Marlfield, 34. Kerloge, 35. Granny, 36. Newrath, 37. Pepperhill, 38. Ballinglanna North, 39. Gortore, 40. Curraghprevin, 41. Barnagore, 42. Ballinaspig More.

early phase of introduction and/or colonization. Significantly, however, no further secure records of early, dated, domesticated animal remains have been forthcoming (*cf.* Milner, 2010) that do not suffer from large age ranges (e.g. cattle bone from Kilgreaney Cave and sheep bone from Dalkey Island; Woodman et al. 1997). As Sheridan has argued (2010), perhaps the evidence from Ferriter's Cove represents an early phase of 'failed' colonisation. Whittle (2007), on the other hand, has suggested that the Ferriter's Cove evidence could represent the remains of a joint of meat, from either wild or domesticated cattle, transported to Ireland from Britain or the Continent, and may not be indicative of an early colonisation phase. The palaeoecological evidence does not strongly favour an early phase of colonisation. Controversial records of possible pre-Elm Decline cereal pollen (i.e. pre-4000 cal BC) from a variety of sites (e.g. Edwards and Hirons, 1984) have not been confirmed with dated macro-botanical cereal remains and thus remain questionable (*cf.* Monk, 2000; Behre, 2007). With some exceptions (e.g. Edwards and Hirons, 1984), there have been few attempts to examine in detail the nature of the Late Mesolithic Irish pollen record using high resolution pollen and charcoal counts, supported by a rigorous radiometric dating programme. Such an approach might reveal with greater clarity any possible agricultural indicators associated with an early phase of colonisation. Moreover, any 'failed' colonisation episode may be, by its very nature, extremely ephemeral and difficult to identify palynologically. Published dates for charred cereal grains for Britain and Ireland suggest that there is no evidence for cultivars prior to 4000 cal BC, with only very limited evidence of cultivation from 3950 to 3800 cal BC, and a marked increase from 3800 cal BC (Brown, 2007). Note, however, that there are difficulties concerning the reliability of some of the earliest dates used in Brown's study because of old wood effects (some dates are, in fact, based on associated charcoal, rather than cereal grains), whilst the date ranges associated with some of the earlier sites can be considerable.

Whatever the timing and actual mechanisms by which cultivars and domesticates arrive, Cooney et al. (2011) argue that there is more permanent settlement in Ireland from c. 3900–3700 cal BC. Several recent projects have made important contributions to our understanding of the island's Neolithic archaeology (e.g. Smyth, 2006, 2007, 2010; Bradley, 2007; Cooney et al. 2011), whilst the application of large-scale archaeological dating programmes using Bayesian statistical modelling is providing much finer-grained chronologies (Bayliss and Whittle, 2007; Whittle et al. 2007, 2011; Cooney et al. 2011; Schulting et al. 2011). Approximately 80 early rectangular houses from some 50 sites have been excavated (Cooney, 2000; Grogan, 2004; Smyth, 2006, 2007, 2010). The orthodox view is that these structures functioned primarily as domestic dwellings (Smyth, 2010, 5). The rectangular houses have been dated to *3715–3625 cal BC* on the basis of an initial Bayesian analysis of 18 published 'gold standard' radiocarbon dates from short-lived materials (McSparron, 2008), with further refinements by Cooney et al. (2011, 598). Several sites include multiple houses (e.g. Corbally, Co. Kildare; Purcell, 2002), although the sequence and duration of the various structures is not altogether clear. Portal and court tombs belong to the same period, although neither of these monument types have been as thoroughly dated as the settlement sites. The chronology of portal tombs is particularly uncertain, although there is an emerging consensus that they fall comparatively early in the Neolithic (Kytmannow, 2008; Cooney et al. 2011; Schulting, submitted). Court tomb construction began from c. 3700 cal BC, and their use continued far longer than that of the rectangular houses (Schulting et al. 2011).

Charred cereals are associated with many of these rectangular houses, but none have yielded significant assemblages of unburnt animal bone due to the generally acidic nature of the soils. Thus, very little is known about the exploitation of animals during this period (McCormick, 2007). Many of the available faunal assemblages derive from funerary contexts, but such material can be problematic, as it is often difficult to assess if the material is contemporary with tomb construction or if it is intrusive (e.g. later insertions; burrowing by small mammals) (Schulting et al. 2011; McCormick, pers. comm). The main domesticates – cattle, sheep/goat and pig – dominate at settlement sites, and invariably comprise well in excess of 90% of the identified mammal bone, including at the constructed platforms at Cherryville and Clowanstown (Breen, 2009; McCormick, 1986, 2007; Mossop and Mossop, 2009). Wild mammals are also represented, including bear, wild cat, deer, rodent, wolf and bird, but again dating is an issue. The Middle Neolithic enclosure site at Kilshane provides an exceptionally large animal bone assemblage, completely dominated by cattle (essentially 100%), demonstrating their importance in ceremonial or ritual sacrifice, feasting or a combination of these (McCormick, in press). The economic and symbolic importance of cattle is a wider feature of the northwest European Neolithic (Ray and Thomas, 2003; Schulting, 2008, in press).

Much of the plant macrofossil data remain unpublished. A preliminary review (McClatchie, accepted) revealed a considerable number of such assemblages in the 'grey literature'. While wheat (mainly emmer wheat) was predominant in the Neolithic, barley (naked and indeterminate) was also recorded. A review of associated arable weeds has never been undertaken for this period in Ireland, despite its potential to provide important insights into farming practices (*cf.* Bogaard, 2002, 2004). Thus, current perspectives on the earliest agriculture are based on a limited published dataset (e.g. Colledge et al. 2005; Jones and Rowley Conwy, 2007). A recent evaluation of the Scottish archaeobotanical record (Bishop et al. 2009) has highlighted its spatial and temporal diversity. However, where the Irish evidence is considered, reference to only a handful of sites (e.g. Tankardstown; Gowen, 1987) creates an over-reliance on them to provide a framework for Neolithic farming *throughout* Ireland.

The major palynological event associated with the onset of agriculture, traditionally placed at c. 4000 cal BC, is the Elm Decline. This is characterised by a decline in the presence of Elm in many pollen diagrams across north-western Europe. In Ireland, the event is frequently accompanied by some of the first, indisputable evidence for agriculture, linking it to anthropogenic activities (Pilcher and Smith, 1979); more recently, other explanations have been proposed (e.g. a climatic event or a pathogen similar to the recent Dutch Elm Disease). Despite providing a range of over 1000 years (*4442–3122 cal BC*, 95% probability), Parker et al. (2002, 28) conclude that the Elm Decline was a 'catastrophic, uniform phased event'. Pollen work associated with the Céide Fields (Caulfield, 1983; Molloy and O'Connell, 1987) indicates a change in the use of landscapes in order to support the 'new economy'. At this site, there is strong evidence for extensive forest clearance (Molloy and O'Connell, 1995; O' and Molloy, 2001), but elsewhere the situation is much less clear, with more ambiguous episodes of clearance or very low levels of activity (e.g. O'Connell and Molloy, 2001; Mighall et al. 2008). Indeed, the diversity we see within the published pollen record suggests that organisation of the landscape varied regionally and temporally.

Climate change has been implicated in the transition to agriculture in north-west Europe (cf. Bonsall et al. 2002) and has become the focus of several recent investigations (e.g. Caseldine et al. 2005; Verrill and Tipping, 2010). Tipping (2010) has argued that many records suggest that the climate of north-west Europe became wetter in the first half of the 5th millennium BC, followed by a significantly drier period until c. 3900 cal BC and again from c. 3850 cal BC, persisting until at least 3650 cal BC. Schulting (2010),

however, rightly draws attention to the spatial and temporal uncertainty associated with many of these records and notes that interpreting cause and effect is far from straightforward in such circumstances. The sensitivity of Irish palaeoecological records, especially the bog oak record (Baillie, 1995, 1999; Turney et al. 2006; Barratt, 2007), provides an opportunity to examine the wider environmental context of farming within a secure chronological framework. Recent work on dendrochronologically-dated bog oaks from around the Lough Neagh basin suggests that Ireland was affected by a series of climatically-driven hydrological changes between 4100 and 3200 BC (Barratt et al., submitted): drier conditions are indicated from c. 4100 BC, with wetter conditions evident from 3620 BC, lasting about 300 years. Caseldine et al. (2005) record an extreme climatic event interpreted as indicating increased storminess on Achill Island, Co. Mayo, at c. 3200 cal BC whilst Baillie and Munro (1988) identified a period c. 3190 cal BC when a series of narrow tree rings show evidence for a severe climate downturn. These data suggest that the second half of the 4th millennium was a time of climate uncertainty.

2. Material and methods: integrating data strands and sources

Chronological (radiometric dates), archaeological (settlement site location data), environmental (archaeobotanical and some zooarchaeological records), and palaeoecological (pollen stratigraphies, radiocarbon dates; bog-oak dendrochronological population data) evidence was collated from published and unpublished (mostly 'grey' literature from contract archaeology) sources. Primary sources included the Irish Excavations Bulletin, the National Roads Authority Archaeological Database, unpublished theses, published sources, and consultation with various private-sector archaeological companies. Radiocarbon determinations were obtained via databases (e.g. CBA Radiocarbon Database), published lists (e.g. Chapple, 2008), and published and unpublished site reports and monographs, whilst dendrochronological data were obtained from Barratt (2007; Barratt et al., submitted) and archives held at Queen's University Belfast.

A re-evaluation of the chronology of the Irish Neolithic was undertaken, placing archaeological, archaeobotanical remains and palaeoenvironmental data on a common time-scale. Few studies have attempted to age-model both environmental and archaeological ^{14}C data, in tandem, on the scale that we have undertaken here (though the focus of the Bayesian modelling of the archaeological data is restricted to results from settlements). New tools (e.g. 'Bchron', 'OxCal' and 'BPeat') enable sophisticated Bayesian chronological age models to be constructed for palaeoecological sites (Blaauw and Christen, 2005; Bronk Ramsey, 2008; Parnell et al. 2008). However, the use of different approaches to chronology construction (e.g. linear interpolation, 'tuning') has resulted in varying degrees of chronological quality, making direct comparisons between results from different sites problematic. Thus, new age models were developed for all palaeoecological sites using the same, unified method. Radiocarbon dates were calibrated (IntCal, 2009; Reimer et al. 2009) in OxCal 4.1 (https://c14.arch.ox.ac.uk/oxcal/) and date ranges reported at 95.4% probability unless otherwise noted. Bayesian modelling was used to refine all archaeological and palaeoecological chronologies, using OxCal 4.1 (Bronk Ramsey, 2008). This approach facilitated more precise assessment of spatial and temporal relationships between different datasets. Parallel age-depth models were also run in Bchron (Parnell et al. 2008) during the early stages of the process but were found to be computationally too time-consuming. Modelled date ranges are rounded to the nearest decade, and are presented in italics, following accepted practice (Bayliss et al. 2007a).

A total of 187 new AMS ^{14}C dates (Supplementary Data Table 1) were obtained on short-lived samples (mainly cereal grains; also hazelnut shell, flax seeds, pea and bone), supplemented by a re-evaluation of published and unpublished dates. The new dates were derived from material obtained from research institutions, consultancies and museum collections. Material was selected from a variety of site types, though, in the event, we were limited by what was available. The majority of samples were single-entity, except for a few cases where two or more grains/seeds/shell fragments were required due to their small size. The advantage of dating cereals, hazelnut shell and flax is that they grow within a single year, and therefore do not introduce offsets, unlike wood or charcoal that can produce offsets on the order of decades or centuries. Wherever possible, paired samples were taken from each context of interest. This allowed an assessment of the synchroneity of the sampled contexts, many of which would have likely been open for an unknown period (e.g., slot trenches of rectangular houses, internal and external pits, etc.), and therefore capable of accumulating material relating to more than a single episode of activity. The availability of multiple dates improved the precision of the Bayesian modelling and also provided an indication of the reliability of results through replication (Buck et al. 1996; Bayliss et al. 2007b; Bronk Ramsey, 2009a,b).

This evaluation was undertaken to: i) establish the chronology of phases and activities at individual sites; ii) compare archaeological events at different sites; iii) examine the timing of the earliest evidence of agriculture and its subsequent development and iv) facilitate comparison between site-specific information and landscape palaeoecological events. Sites and site phases were assigned a chronological period on the basis of the central tendency (characterised by mode) of the calibrated date range in those cases where a Bayesian model was constructed. Where too few determinations (i.e. <5) were available for any single site/phase to justify Bayesian modelling, sites were assigned to one or more phases based on individual calibrated dates, or, where justified, by a site average using the 'R-combine' function in OxCal 4.1. Chronological periods used are shown in Table 1. Sites that could not be placed into one of the categories because of poor dating control were assigned to an overall 'Neolithic' category.

Summed radiocarbon calibrations were used to summarise archaeological accounts of prehistoric settlement and assess the fluctuating levels of human activity over time. The technique involves the arithmetic addition of the calibrated probability mass functions for a set of radiocarbon dates. The approach has been shown to be useful as a broad indicator of demographic patterns (Shennan and Edinborough, 2006; Collard et al. 2010; Williams, 2012) and has allowed us to use these data as a visual tool to assist comparing archaeological with palaeoenvironmental and climatic records. The number of dates used in the analysis varied between 740 and 870 ^{14}C dates (analysis dependant; see captions Figs. 19 and 20); this comfortably exceeds the recommended sample size of 500 (Williams, 2012) needed to create a sufficiently large regional sample to mitigate site and period level biases.

An evaluation of Neolithic archaeological settlement was undertaken in tandem with the chronological analyses, making use of

Table 1
Chronological categories utilized.

Period	Short name	Dates
Early Neolithic I	EN I	≥4000–3750 cal BC
Early Neolithic II	EN II	3750–3600 cal BC
Middle Neolithic I	MN I	3600–3400 cal BC
Middle Neolithic II	MN II	3400–3100 cal BC
Late Neolithic	LN	3100–2500 cal BC

published sources, public records (e.g. Sites and Monuments Records) and unpublished data. A relational database was constructed to query the data and displayed as a series of GIS maps in chronological time slices. We focused on the spatial–temporal patterns of settlement during the study period to address questions concerning the extent of human occupation across the landscape, amassing a list of 375 excavated sites that have produced Neolithic material (as of summer 2010). Sites were then broadly categorised as 'houses', 'possible structures', 'enclosures', 'midden', 'industry' (including quarry sites), 'burnt mounds', 'burials' and 'pits, etc.'. Sites lacking ^{14}C dates were assigned broad categories on the basis of artefactual evidence. Each dated site was categorized into one of three groups based on whether short-lived seeds/nutshell, bone or charcoal dates were available.

An assessment of the Neolithic archaeobotanical record (cereal grains and chaff, weed seeds, fruit stones and nutshell) was undertaken. Data were collated from published and unpublished archaeobotanical reports associated with archaeological excavations. Fully quantified lists of plant taxa were available from most excavations, but in some cases remains had been recorded on a presence/absence basis or on a scale of abundance. A relational database was developed (McClatchie et al. 2014) and archaeobotanical data inputted at context level. The new dating programme and re-interpretation of existing dates determined the assignment of sites into the chronological categories introduced above. The data were analysed by reference to location, context and type of plant remains recorded, paying attention to temporal trends. Analyses of potential arable weed data were carried out to investigate crop management practices (cf. Bogaard, 2004), using Ellenberg et al.'s (1992) ecological groupings (McClatchie et al. 2014).

The scale of landscape clearance and associated vegetational responses during the Neolithic and its spatio-temporal dimensions were investigated via a re-evaluation of palaeoenvironmental and associated radiocarbon data. Pollen evidence from multiple sites was collated and placed on a common time scale. The Irish Pollen Database (as it stood in 2004; now accessible and updated from www.ipol.ie) provided a starting point. The database at the time contained locational and basic temporal data for over 400 dated and undated pollen diagrams in Ireland. This dataset was heavily augmented by additional data collection: radiocarbon dates, stratigraphic information, scanned pollen diagrams and counts (where obtainable). Sites were evaluated in terms of their pollen resolution for the period of interest and whether there were sufficient radiocarbon dates to construct reliable age models. Following initial screening, new age models using Bayesian approaches were developed. Multiple models were created for each site within and between programs (e.g. OxCal and BChron), until one or more were selected as the working master(s). About 700 iterative age models were developed as part of this process (Barratt et al. in prep.).

We examined the timing of vegetational palynological 'events' whose response appears to be linked directly or indirectly to the onset of agriculture and land clearance and dated these horizons of interest using the aforementioned approaches: the Elm Decline(s) (*Ulmus*), and ribwort plantain's (*Plantago lanceolata* L.) 'Start', 'Rise', and 'Decline'. The starts of the first and second Elm Declines (*sensu* Hirons and Edwards, 1986) were selected for age-modelling, defined as the point at which Elm pollen starts to decline. The *Plantago lanceolata* 'Rise' is defined by the sustained appearance or increase of the pollen type in Neolithic diagrams – the herb is clearly already present at many sites, at low or intermittent levels – this was seen as a possible proxy for anthropogenic disturbance. In many diagrams, the initial 'Start', or 'Rise' in *Plantago lanceolata* pollen values is followed by its decline to low levels or its temporary disappearance: the 'Start' of this decline (the '*Plantago* Gap') has also been modelled. Several other vegetational events were also dated but are not considered here (the rise of ash (*Fraxinus*), pine (*Pinus*) declines and behaviour of hazel (*Corylus avellana*), Barratt et al., in prep.). We also examined the behaviour of Poaceae (grasses) but found that many of the records used are from mires where grasses occur naturally; this pollen type was highly variable within records. We did not select the first appearance of cereal-type pollen in diagrams because of the uncertainty in their identification as *cereal* pollen (O'Connell, 1987; Hall et al. 1993; Tweddle et al. 2005; Behre, 2007). The new age models and associated 'pollen events' allowed us to more precisely date the timing and longevity of the selected environmental events and their spatial spreads. Other proxy environmental data were also collated, in particular Irish dendrochronological population data, which appears to reflect wider climatic and hydrological changes at this time (Barratt, 2007; Barratt et al., submitted), in addition to data associated with climatic changes in the North Atlantic region (e.g. ice core data, O'Brien et al., 1995; ice-rafted debris (IRD) events, Bond et al. 2001).

The broad-scale patterns of environmental and vegetational changes inferred from these palaeoenvironmental records were compared with evidence from the economic and settlement strands of the project. Importantly, all records have been re-evaluated carefully in terms of their chronological accuracy to establish the timings of activities across the various records and explore any potential relationships.

3. Results

3.1. Neolithic settlement: chronological considerations

The 187 new AMS ^{14}C determinations (see Supplementary Data Table 1) form an important body of high-quality dating evidence, with the majority (172) being on annually produced entities (charred cereal grains, hazelnut shells and flax seeds), together with a smaller number (15) of domestic animal and human bone samples. Wherever possible, duplicate samples were dated from each context of interest. The effects of this approach can be seen in the results from a rectangular structure at Caw, Co. Derry (Table 1). There is excellent agreement between the paired charred wheat grains dated both within and between contexts (though note that the two *Hordeum* results from a posthole just fail to combine (χ^2, $T = 6.0$ (5%, 3.8)). The previously available charcoal based ^{14}C date from the structure's north wall slot (Bowen, unpublished data) demonstrates the old-wood effect, though it is relatively subtle here; the difference is far greater in a number of other cases. Throughout the dating programme, we found duplicate cereal dates generally gave very consistent results and highlighted issues with existing charcoal dates. Nevertheless, the corpus of existing charcoal determinations can be included in the construction of Bayesian models, either by treating them as *termini post quos* (*cf.* Bayliss and Whittle, 2007a), or, as preferred here, by entering them as 'charcoal outliers' in OxCal 4.1 (Bronk Ramsey, 2009b) (Fig. 2).

Over 50% of the dates obtained are associated with rectangular houses. There were two main objectives in the dating of these structures. The first was to confirm and if possible to refine McSparron's (2008) chronology. While sites from across the island were included in that study, each individual structure was represented by only one or at most two determinations. The second objective was to determine whether a finer-resolution sequence of periods of use could be detected at sites with multiple rectangular houses (Schulting et al. in preparation). The project results, combined with those previously published, provide a total of 126 determinations on charred cereals and hazelnut shells only (i.e., excluding all charcoal samples), from 30 individual rectangular houses from 20 sites (Fig. 3). The resulting Bayesian model

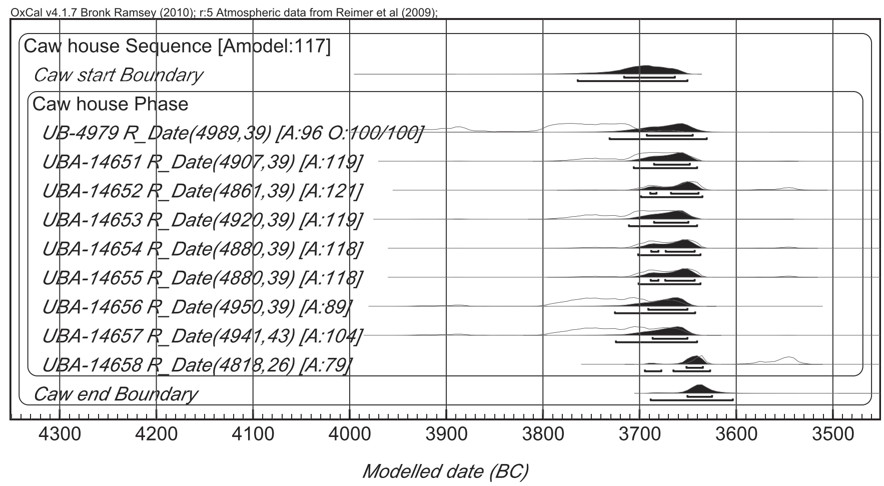

Fig. 2. Paired charred cereal dates from single contexts at Caw, Co. Derry. The first date shown (UB-4979) is based on bulk charcoal and treated as a 'charcoal outlier' in the model; the other dates are based on short-lived seeds (See Supplementary Table 1).

emphatically confirms the existence of a distinct 'house horizon', starting *3720–3680 cal BC*, ending *3640–3620 cal BC*, encompassing just *40-100 years*. While the overall range is very similar to McSparron (2008) and recent work by Cooney et al. (2011), the estimated start and end ranges for the Neolithic rectangular 'house horizon' have been further constrained and are based on a considerably expanded dataset of high-quality dates. The dating of the use of these buildings to just a few generations has important ramifications for our understanding of all aspects of Neolithic society.

Pit and post-hole complexes (hereafter abbreviated as 'pit complexes') are a diverse category, comprising sites with varying numbers of pits, post- and stake-holes and spreads of midden material, but lacking clear structural remains. These unenclosed sites have no above-ground remains and are therefore usually chance discoveries made during developer-led work; indeed, they have been discovered in many places where development projects have occurred in Ireland. They may comprise one or two features of Neolithic date (e.g. Harristown Big 2; Tierney and Johnston, 2009) or extensive groups of related features sometimes found on multi-period sites (e.g. Kilmainham 1C; Walsh, 2009).'Pit complexes' (start: *3710–3660* cal BC; end: *3520–3460 cal BC*) overlap in part with the 'house horizon' but persist for significantly longer (Fig. 4). They may be architecturally associated with round houses (Smyth, 2010), though no such structures were identified in any of the sites dated here. One of the problems we encountered is that sites with Neolithic rectangular houses have been sampled far more intensively for archaeobotanical remains, and so provided more opportunities for the ^{14}C samples that formed the project's primary focus; less-structured pit complexes have received less research and sampling attention (see Smyth, 2012).

While the dating of the 'pit complexes' is based on a relatively small number of determinations ($n = 37$), additional support comes from 69 high-quality AMS ^{14}C determinations from the Neolithic settlement at Tullahedy, Co. Tipperary (Cleary and Kelleher, 2011; Schulting, 2011). Three rectangular houses and a palisade from this site can be assigned to the earlier Neolithic 'house horizon', while contemporary activity in the form of a series of pits and postholes but no other clear structures, also continues significantly later. Overall, activity at Tullahedy is modelled as starting *3675–3645 cal BC*, ending *3510–3460 cal BC* (Schulting, 2011). The chronological similarity to the proposed pit complex phase is striking.

Turning to the evaluation of Neolithic settlement data, we undertook a comprehensive collation of dated and undated sites (Fig. 5), resulting in a combined total of 1433 ^{14}C determinations –

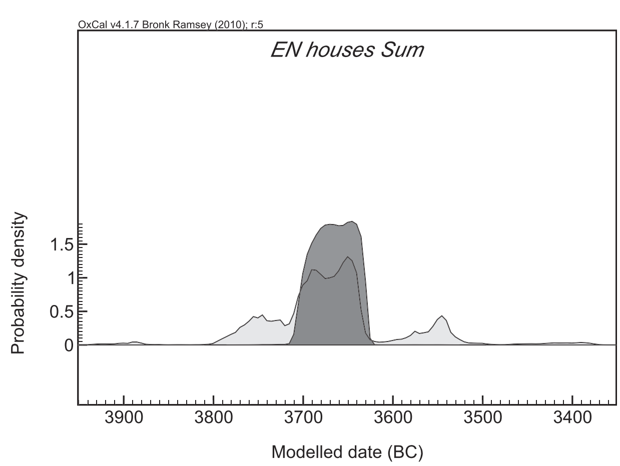

Fig. 3. Modelled summed probability for definite and probable rectangular houses ($n = 126$ dates on short-lived materials, from 20 sites, excluding 3 results identified as outliers in a Bayesian model).

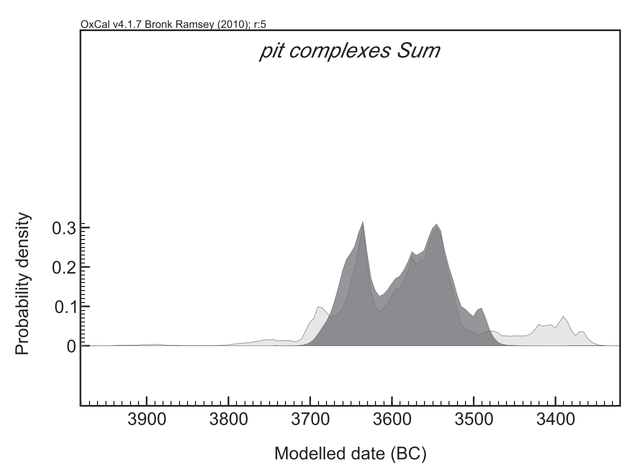

Fig. 4. Modelled summed probability density for sites consisting of pit and posthole complexes ($n = 37$ dates from 10 sites).

of which 824 refer to Neolithic phases – from 184 sites (Figs. 5–9). Some areas, such as the M3 road corridor in County Meath, and the immediate vicinity of Sligo town, on the west coast, have a very high concentration of sites. The patterns of modern-day development thus heavily influence where Neolithic sites are known. The locations of 191 undated excavated sites that have produced demonstrably Neolithic material (e.g. pottery or diagnostic lithic assemblages) were also recorded (Fig. 5a), as were the locations of 730 extant Neolithic megalithic tombs (not shown). For many of the excavated sites that have not been radiocarbon dated, it should be noted that post-excavation analysis was still ongoing in 2010. The predominance of undated pits, postholes and spreads (labelled 'pits etc.') is clear.

Figs. 6–9 summarize the distribution of Neolithic sites for selected time slices. Each site was categorised according to the best available account of its chronology, including Bayesian models where appropriate. A number of sites (including Cherryville, Co. Kildare; Clowanstown, Co. Meath; Corbally, Co. Kildare; Magheraboy, Co. Sligo; Monanny, Co. Monaghan; Knowth, Co. Meath) that have early charcoal dates were not included in the EN I category because short-lived samples place them in a later period (e.g. EN II). At Magheraboy causewayed enclosure (Danagher and Cagney, 2005; Danaher, 2007) for example, only two dates on short-lived samples are available – one cereal grain and one hazelnut shell. These are, however, significantly later than the series of charcoal determinations that have been used to (tentatively) propose an early date for the site (Cooney et al. 2011). Magheraboy is therefore not included on the EN I map because its short-lived specimens fall within EN II. As noted by Cooney et al. (2011), further work is needed on this key site, since if it is indeed this early (and the charcoal samples were carefully selected), this has major implications for our understanding of the Neolithic in both Ireland and Britain, as it is also significantly earlier than any of the dated British causewayed enclosures (Whittle et al. 2011).

Charcoal dates were used to categorise sites with no other dated material. The "old-wood" effect pushes a number of rectangular house sites into EN I, as shown in Fig. 6a (Mullaghbuoy, Ballyharry, Ballymoney and Ballygalley – all in Co. Antrim, Newtown, Co. Meath and Donaghmore, Co. Louth). With the exceptions of Ballymoney and Donaghmore, some of the charcoal dates for these sites also fall into EN II. The evidence for a clear Neolithic 'house horizon' is now irrefutable, as discussed above, and it is almost certain that all these sites actually date to EN II, 3750–3600 cal BC. This emphasizes a major problem with charcoal dates: although they can provide useable results, often they are simply too old.

A clear contrast can be seen between Fig. 6a, where every dated site older than 3750 cal BC is plotted regardless of material date, and Fig. 6b, showing the distribution of EN I sites dated using short-lived samples only, resulting in only two sites. Tinryland is included here as one hazelnut shell from the fill of a natural depression produced a date of 4046–3968 cal BC (5210 ± 24 BP, UBA-8828) (O'Connell, 2009). However, the fill contained chert artifacts that

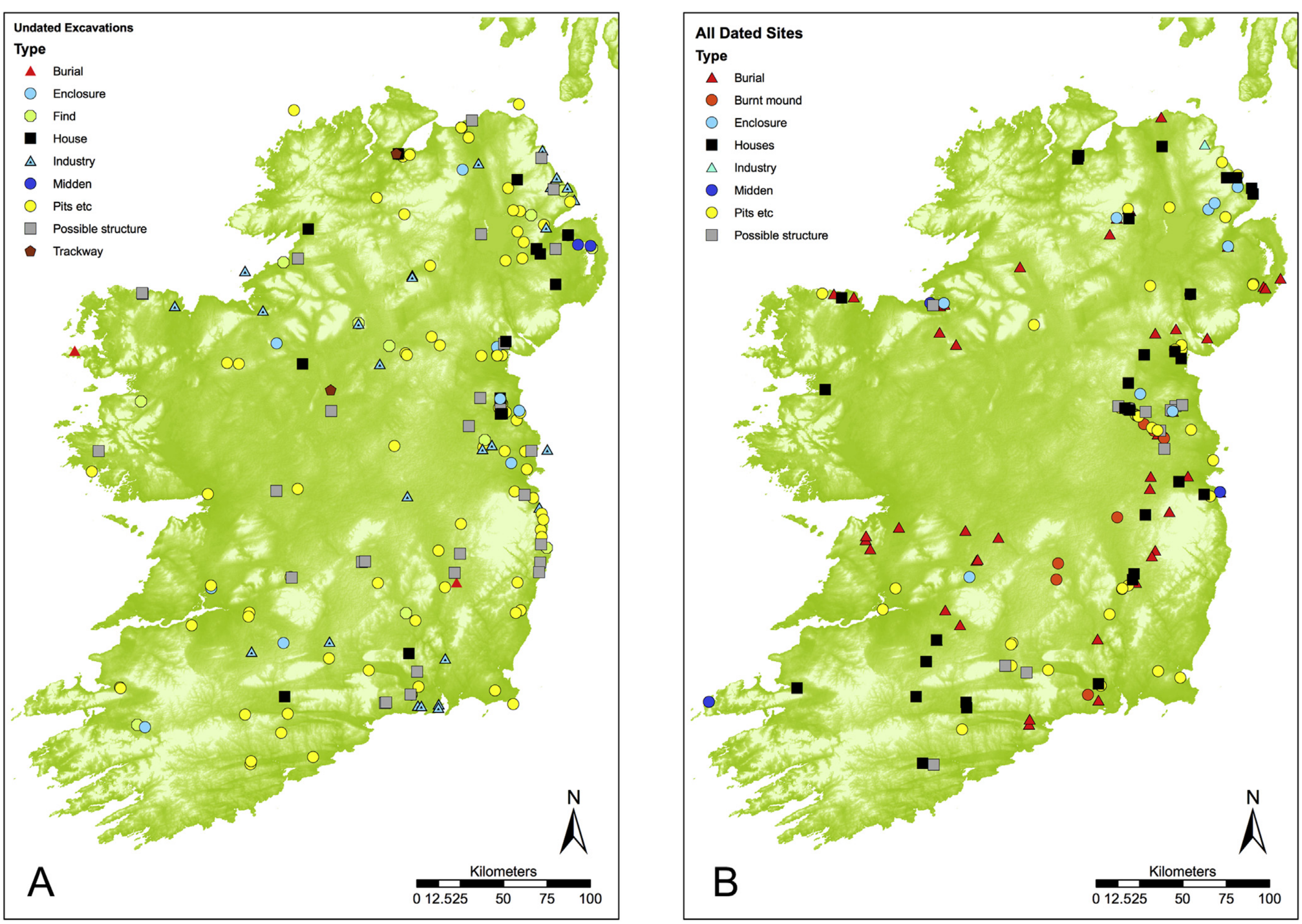

Fig. 5. The distributions of undated (a: left) and dated (b: right) excavated Neolithic sites in Ireland (excluding megalithic tombs).

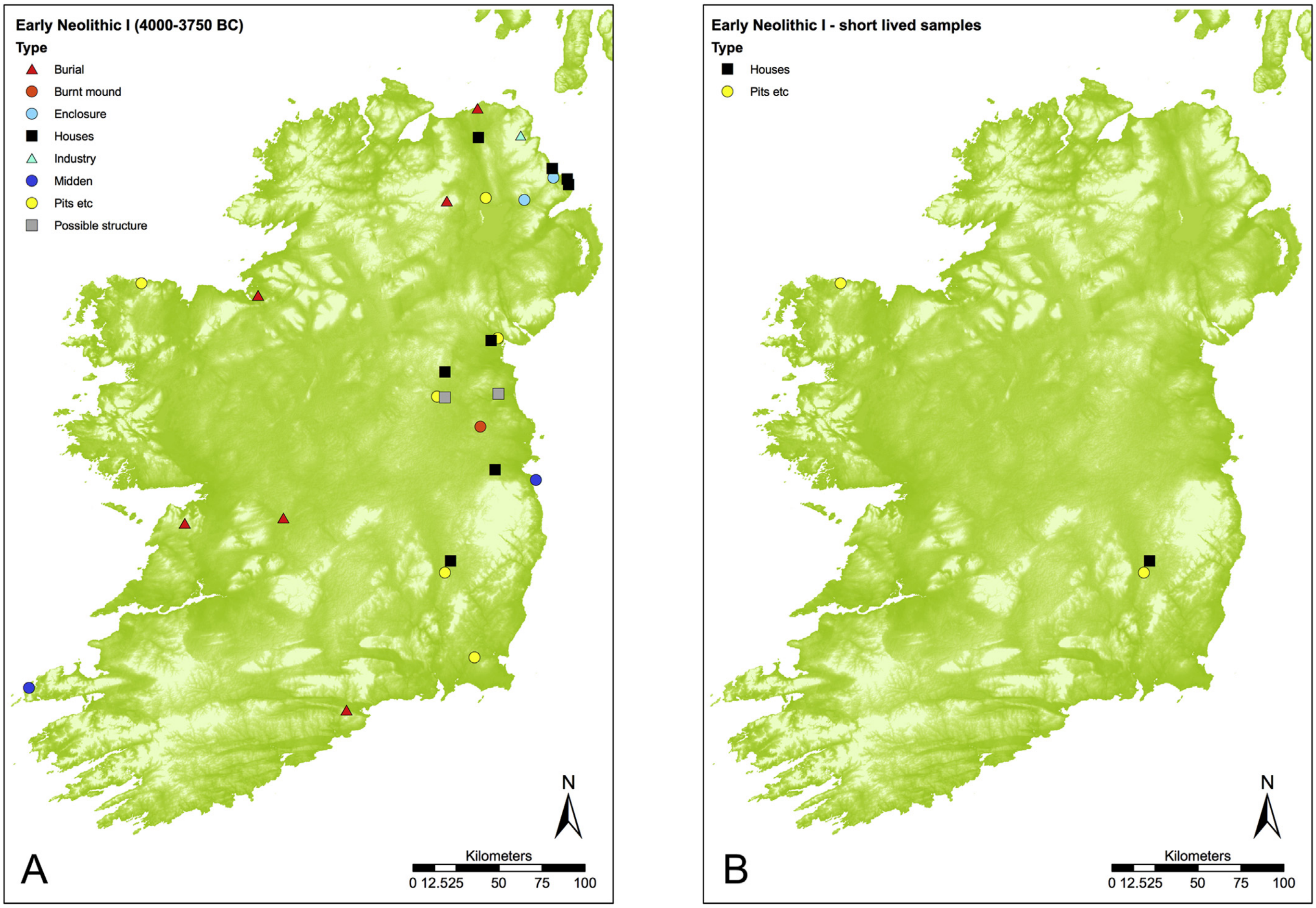

Fig. 6. Distribution of sites dating to the Early Neolithic I period (≥4000–3750 cal BC) (a. left: all dates; b. right: short-lived samples).

were described as ‘Late Mesolithic’, and although the excavator argued that some Early Neolithic stone tool assemblages also appear Mesolithic in character (O'Connell, 2009, 24), it seems likely that this date actually refers to Late Mesolithic activity. A similar explanation may apply to the dates from Belderrig, Co. Mayo, where there is evidence for both Late Mesolithic and EN II activity (Warren, 2008).

EN II, in contrast, shows Ireland richly populated with sites (Fig. 7) – not just rectangular houses, but also burials, pit complexes, burnt mounds, enclosures, and coastal middens. Although some of these sites also suffer from poor chronological control, it is important to recognize that there is a considerable variety of sites dating between 3750 and 3600 cal BC, a point also recognized by Cooney et al. (2011, 668) in their recent re-evaluation. This period saw a veritable explosion in the number and variety of sites across the island, including both domestic and ritual (funerary) architecture (Schulting et al. 2011), as well as large enclosures such as that at Donegore Hill, Co. Antrim, in use between *3855–3665 cal BC* and *3590–3430 cal BC* (Mallory et al. 2011).

There is generally much reduced evidence for human settlement in the Middle and Late Neolithic compared to the EN II period (Figs. 8 and 9). During the Middle Neolithic II period in particular, the most frequently encountered sites relate to burials of the passage tomb tradition. Although single charcoal determinations are available from a small number of settlement sites, the dates and their contextual relationships are of low quality. Therefore, aside from passage tombs themselves, the evidence for settlement during 3400 to 3100 cal BC is very limited indeed.

The Late Neolithic (LN) (Fig. 9) comprises mainly Grooved Ware sites and various enclosures, the latter showing a pronounced northern and eastern bias in their distribution. The same old-wood issues that confuse the Early Neolithic also apply to the Late Neolithic – except here the errant dates are charcoal samples from otherwise Bronze Age sites.

3.2. Plant macro-remains analyses

Fifty-two sites were recorded onto a database (Fig. 10), around two-thirds of which were unpublished at the time of final data entry (November 2010) (McClatchie et al. 2014). Most plant remains were preserved as a result of charring, though waterlogged remains were recorded from a handful of sites (Clowanstown 1 burnt mounds; turf layers at Newgrange passage tomb, Co. Meath; ditch fills at Rathdooney Beg barrow, Co. Sligo). A further 17 Neolithic sites were identified where cereals were present, but the final excavation reports had not been completed at the time of data entry. The distribution of sites suggests an apparent eastern and southern bias (Fig. 10), but this is strongly influenced by the locations of recent infrastructural developments.

No sites with plant remains could be securely dated to EN I, while 28 sites with plant remains were dated to EN II, of which the majority (17) were rectangular houses, both single and multiple.

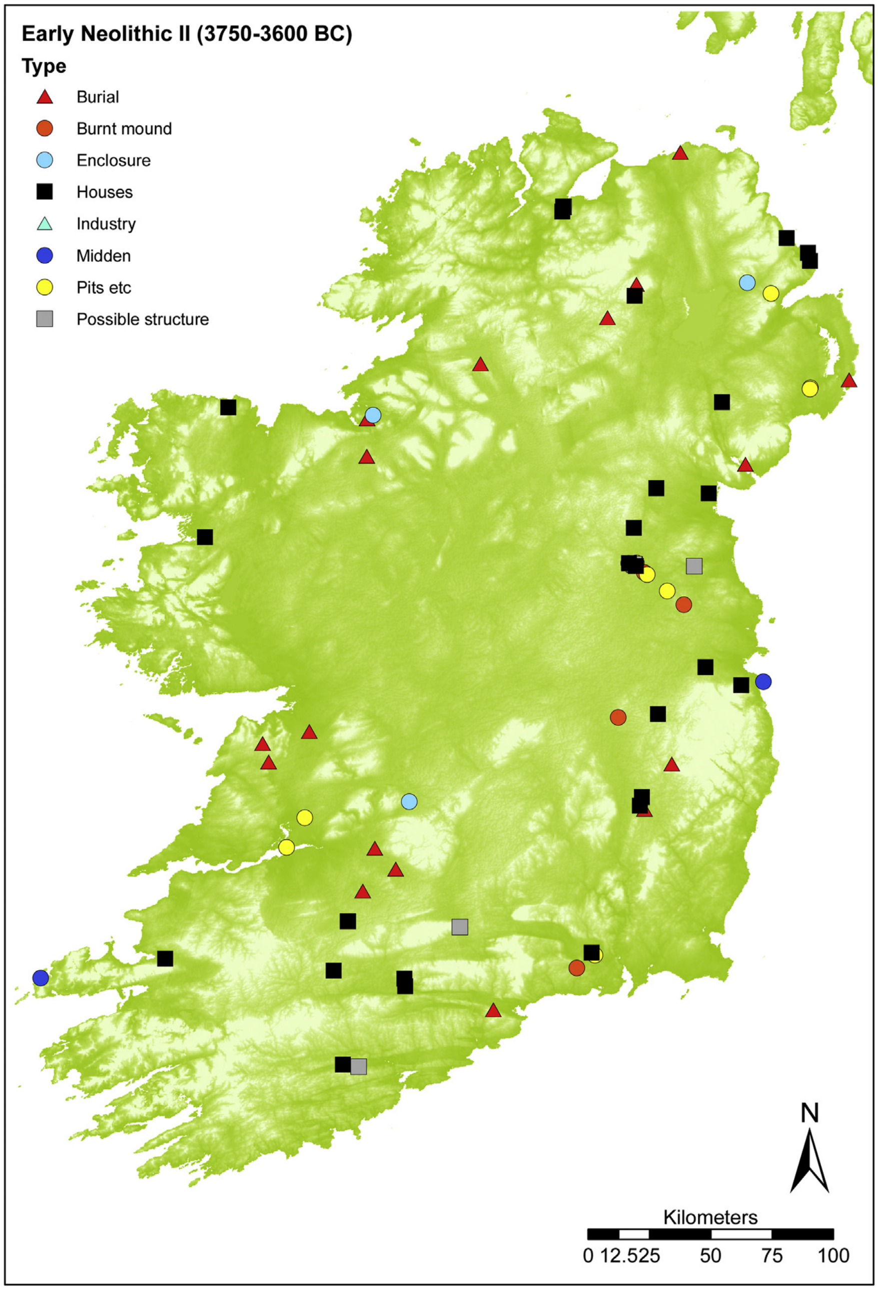

Fig. 7. Distribution of sites dating to the Early Neolithic II (3750–3600 cal BC).

Ten sites were dated to MN I, mostly 'pit complexes' as well as a passage tomb (Baltinglass, Co. Wicklow). Eleven sites were dated to MN II–LN (pit/post-hole complexes, structures and possible structures, and two passage tombs: MN II Newgrange and Knowth, Co. Meath). Further details on the specific sites and their associated dating are forthcoming (McClatchie et al., in preparation).

The earliest dated cereals occur at EN II sites, with the single earliest example being a grain of emmer wheat from House 1 at Tankardstown South, Co. Limerick (3942–3707 cal BC; UBA-14739: 5013 ± 31 BP). Cereals were recorded at 86% of EN II sites (24/28 sites) and 90% of MNI sites (9/10 sites); there appears to be a reduction (to 36%; 4/11 sites) in their occurrence at MN II–LN sites (Fig. 11). Cereal remains usually consisted of grains – chaff was present at a number of sites, usually in the form of hulled wheat spikelet forks and glume bases, but cereal grains were always dominant (McClatchie et al., 2014). Cereal grains were often recorded in small quantities (1–25 grains), but larger assemblages (>100 grains) also occurred, for example at Tankardstown South houses and Clowanstown 1 burnt mounds (McClatchie et al., 2014). Many of the charred wild plant seeds (other than nut and fruit remains) probably represent arable weeds growing alongside the cereals and inadvertently harvested. Hazelnut shell fragments are present at 93–73% of Neolithic sites, with decreasing levels at MN II-LN sites. Fruit remains such as crab-apple and bramble occur at a significant minority of sites throughout the Neolithic, rising to 36% of MN II–LN sites; the total numbers of finds are often low, except in the case of crab-apple, which is sometimes found in large quantities.

Emmer wheat was dominant amongst the introduced crops, especially during EN II and MN I, but there is also evidence for

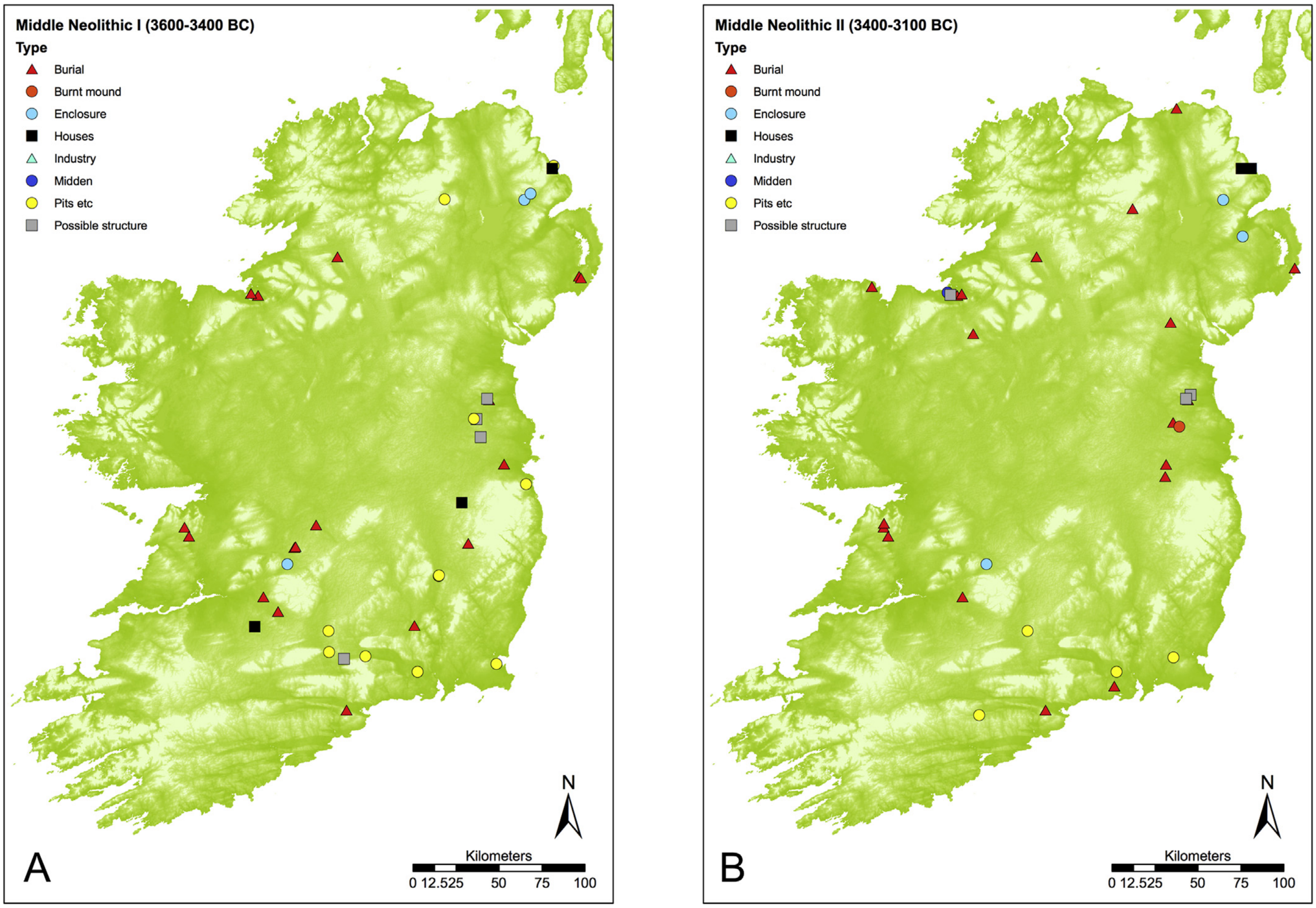

Fig. 8. a,b: Distribution of sites dating to the Middle Neolithic I (3600–3400 cal BC) & II (3400–3100 cal BC). See text on the significance of rectangular houses in this period.

barley and occasional einkorn wheat, naked wheat and flax (Fig. 12). Naked barley was more commonly recorded than hulled barley during EN II. At MN II–LN sites, emmer wheat and naked wheat were present, but the small number of sites prevents any firm conclusions as to which crop was more important at this time. The barley present on these later sites was not identified to type. Oat is likely to have been an arable weed. A single grain of spelt has recently been recorded from Neolithic contexts at Donegore causewayed enclosure (Gouldwell, 2011); spelt is not usually present in significant quantities in Northern Europe until the Bronze Age (Jacomet, 2007). Direct AMS dating would be essential for confirmation. Most individual sites produced evidence for a rather narrow range of crops, but further analysis of the dataset suggests that this might reflect sampling practices, whereby the relatively small number of samples taken at many sites has resulted in a restricted range of crops being recorded (cf. Jones, 1991; McClatchie et al. 2014). There is much evidence for crop usage in the earlier Neolithic period, particularly at rectangular houses and pit/post-hole complexes, with less evidence in the later Neolithic, but far fewer sites date to this period. Many sites also contained evidence for a range of gathered foods, including hazelnuts, apple and bramble. It is worth emphasising that *both* hazelnut and cereal remains are less frequent in the MN II-LN.

Cereals are found at all types of sites, including those that are perceived to have a 'domestic' character (e.g. EN II rectangular houses), as well as sites interpreted as representing locations of more 'ritual' activities, if such a distinction can be made (e.g. Baltinglass, Co. Wicklow) (cf. Bradley, 2005). Cereal-related activities were carried out by a range of communities in a variety of locations and circumstances. Where cereal grains were present, they are often recorded in rather small quantities, presumably charred accidentally, but their persistent occurrence points to widespread use.

Charred weed seeds of potential arable weeds were recorded in many samples (McClatchie et al. 2014). Some assemblages (13) contained sufficient weeds to undertake an analysis of their habitat associations (Fig. 13). The Irish Neolithic dataset is much smaller than that of Britain or Europe, but follows a similar trend (Fig. 13; Bogaard and Jones, 2007, 367), containing mostly species of disturbed habitats and few woodland taxa. Analyses of the life-cycle of weeds from sites in Britain and central Europe show that the proportions of annual and perennial taxa are roughly evenly split, while in Ireland annuals dominate (Fig. 14). The proportions of annual/perennial weed taxa and their ecological characteristics do not resemble those expected for newly cleared plots associated with a shifting cultivation regime, which should be represented by a dominance of perennial taxa, particularly woodland perennials (Bogaard, 2002, 2004).

3.3. Palaeoecological analyses

When the restrictions of a more robust dating methodology were applied to the palaeoecological sites, the number of sites suitable for analysis was considerably reduced to a total of 68

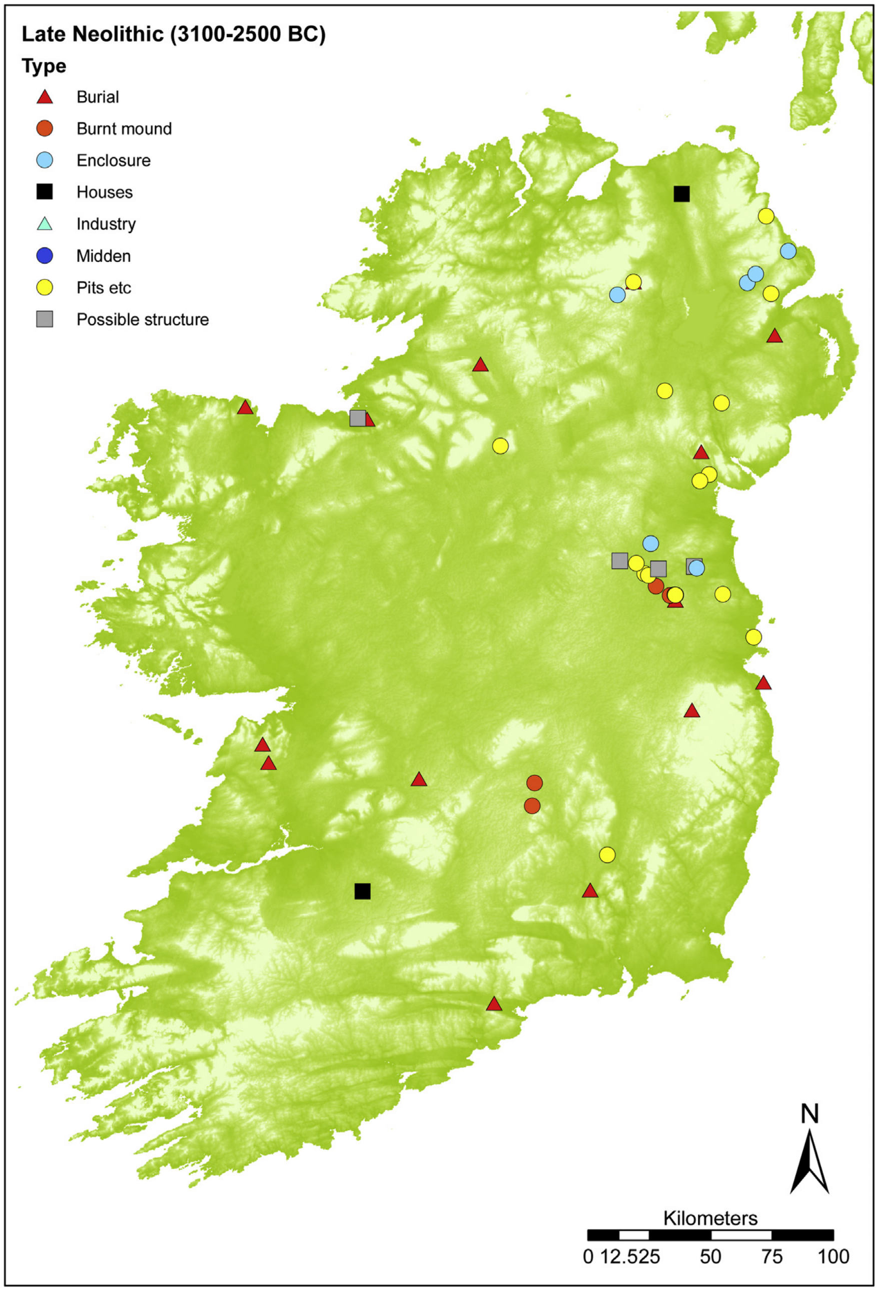

Fig. 9. Distribution of sites dating to the Late Neolithic (3100–2500 cal BC). See text commentary on the significance of rectangular houses in this period.

(Fig. 15). Of these, a further 18 were found to be unsuitable, due to pollen resolution issues, lack of clear agricultural indicators and/or hiatuses; details of these may be found in the Supplementary Data (Table 2).

The Elm Decline was selected for investigation based on its widespread use as a chronological proxy for the start of the Neolithic (O'Connell and Molloy, 2001; Parker et al. 2002) and its well-known temporal association with anthropogenic disturbance. The 'start' of Elm Decline 1 (*sensu* Hirons and Edwards, 1986) is not a synchronous event at the examined sites. If we exclude sites with uncertainty ranges extending over 700 years (grey lines), the total 'start' period lies between *4610–3620 cal BC*, spanning 990 years (this excludes Crocknaraw, Co. Down, an outlier at *2870–2460 cal BC*). The earliest 'start' comes from Derryinver, Co. Mayo (*4610–4090 cal BC*), whilst the latest comes from Crockbrack, Co. Derry (*3630–3190 cal BC*). Such large age ranges for what is putatively a single event are probably associated with poor chronological precision at these sites and reveal little about its 'true' age and/or imply the Elm Decline is asynchronous. Many of the sites with longer and earlier date ranges are from lake systems (e.g. Lough Nabradden, Altar Lough and Lough Nadourcan, Co. Donegal) and there is a strong possibility that old carbon, hard-water effects and reworking of sediments affected their dating. Many were investigated before the common usage of AMS dating, and are based on bulk ^{14}C samples. Other sites have quality issues (e.g. large samples taken at Carrivomoragh, Co. Down; re-working at Ballydoo, Co. Galway) and/or too few dates covering the period of interest (e.g. Bay Farm, Co. Antrim).

More precisely dated sites (black lines) very broadly appear to consist of two groups (A & B) (Fig. 16). Group A sites (Fallahogy to

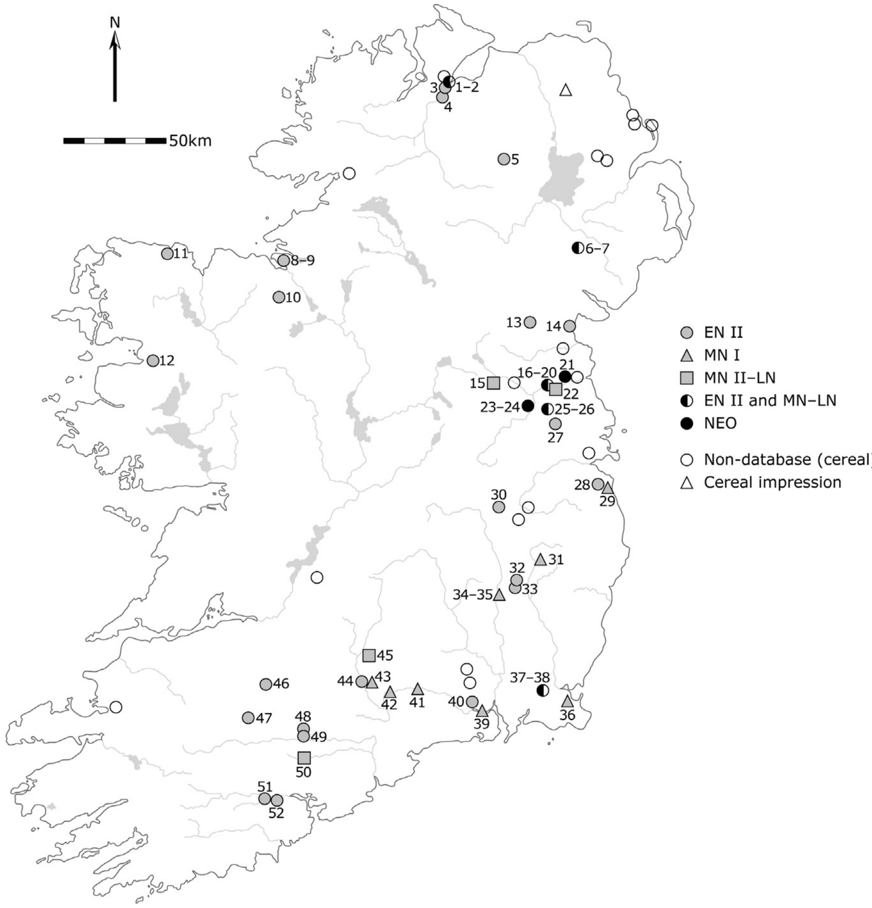

Fig. 10. Locations of Neolithic sites in Ireland where plant macro-remains have been recorded, by chronological category.

Ballynagilly, inclusive), commence at *4350–3780 cal BC*. These northern sites hint at an earlier, regional event compared with the west and east/south of Ireland. The northern sites in Group B (Fig. 16; Ballyscullion to Crockbrack) all show a post-4000 cal BC 'start', mostly EN I, extending in some cases until *3630 cal BC*. In the west, Derryinver, Co. Galway, is clearly temporally separate from the other western sites, starting earlier than the conventional date of the Elm Decline, at c. *4610–4090 cal BC*; however, as a lough site

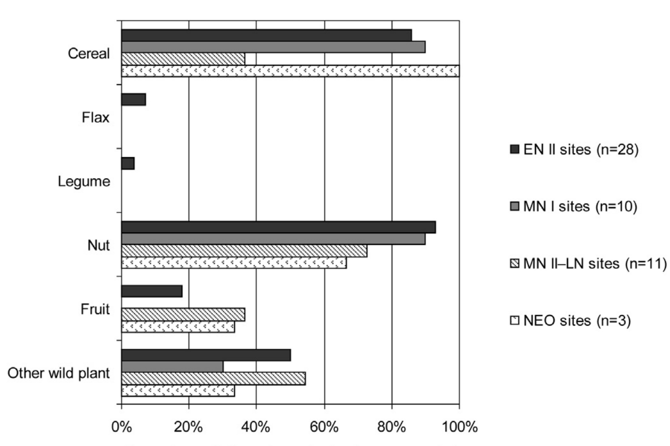

Fig. 11. Relative frequency of plant types recorded at database sites ($n = 52$). "Nut" category consists of *Corylus avellana* L. "Fruit" category consists of *Malus sylvestris* L., *Rubus* spp. (including *R. fruticosus*) and *Sambucus nigra* L. "Other wild plant" category consists of arable and other weeds.

there is the possibility of dating problems, as previously outlined. Many of the better-dated sites from western Ireland (e.g. Lough Sheehauns, Co. Connemara; Lough Aisling, Corslieve Lough, Céide Fields, all Co. Mayo) closely resemble the timing of Group B 'starts' from the north. In the combined south and east group, apart from Moynagh Lough, Co. Meath (*6910–5260 cal BC*), sites show a similar spread.

Plantago lanceolata L. (ribwort plantain) is one of the most important herbaceous plants used to infer human disturbance. Although commonly used to infer pastoral activities, it is also likely to have thrived in primitive arable habitats (Groenman-Van Waateringe, 1986). Its presence as a charred weed in archaeobotanical assemblages (e.g. Donegore Hill, Co. Antrim, Gouldwell, 2011; Clowanstown, Co. Meath, Mossop and Mossop, 2009) attests to its association with arable cultivation. During the Early Neolithic, there is a noticeable rise in *Plantago lanceolata* pollen counts at some sites, whilst at others, very low and intermittent appearances occur. In the latter cases, the values often rise after initial sporadic appearances. The '*Plantago* rise' may therefore date the first appearance of the herb at a site; at others, it denotes a marked increase in its pre-existing presence. However, *Plantago lanceolata* clearly becomes a noticeable part of the pollen record c. 4000 cal BC (Fig. 17). If we exclude lough sites, and the anomalously old date from Garry Bog, all remaining sites suggest that the '*Plantago* rise' occurred no earlier than 4050 cal BC and mostly from 3900 cal BC (Fig. 17).

Following the '*Plantago* rise', a subsequent event occurs, which we name the '*Plantago* Gap' (Fig. 18), and is defined by a decline in abundance or disappearance from the record of the *Plantago* pollen

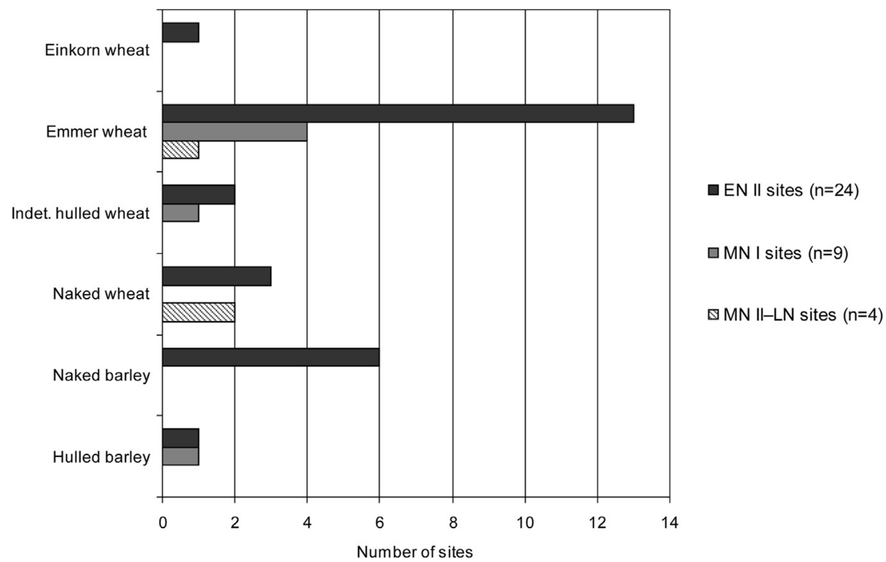

Fig. 12. Relative frequency of wheat and barley types at EN II, MN I & MN II–LN sites where cereals were recorded (sites $n = 37$; records of grain and chaff remains included). For further information on quantities of cereals, see McClatchie et al. 2013.

type and is seen in many sites. This is often concurrent with the lowered presence of other open indicators and increases in arboreal taxa. The decline in this anthropogenic indicator provides a marker for a change from the preceding landscape character. Twelve sites provide age-ranges for this event of less than 700 years. These provide an earliest start date for the decline c. 3500 cal BC. Two further sites, Ballyscullion, Co. Antrim and Lough Sheeauns, Co. Galway, start only c. 60 years earlier (*3570–3100 cal BC* and *3570–3390 cal BC*, respectively). Only three sites (Fallahogy, Co. Antrim; Weir's & Killymaddy Loughs, Co. Tyrone) have a '*Plantago* Gap' starting prior to 3600 cal BC. The earliest of these three sites is Fallahogy, the dates from which do not overlap with the more 'precise' dates from the other 12 sites. Whether this separation is real or the result of the wide and overlapping calibrated ranges of the dates on which Fallahogy's chronology is based upon is unclear. Using just the more precise dataset of 12 sites, the '*Plantago* Gap' appears to occur no earlier than c. 3500 cal BC.

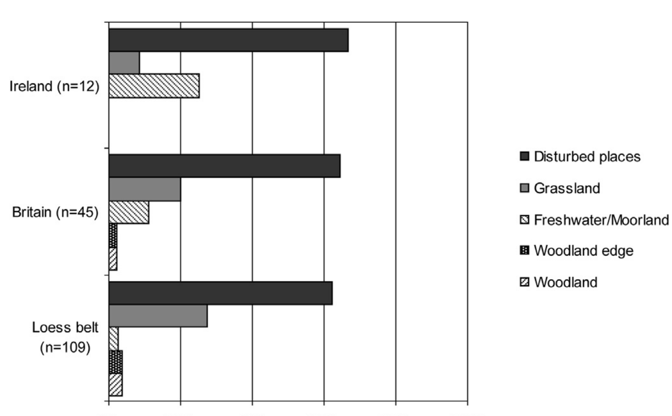

Fig. 13. Major habitat associations of potential arable weed taxa from Neolithic Ireland, Britain and central Europe. Analysis of charred seeds identified to species level; trees/shrubs excluded. Data source for non-Irish results: Bogaard and Jones (2007, in press). Disturbed habitat taxa recorded at Irish sites: *Avena* spp., *Galium aparine* L., *Hyoscyamus niger* L., *Lapsana communis* L., *Lolium temulentum* L., *Polygonum aviculare* L., *Raphanus raphanistrum* L., *Tripleurospermum inodorum* (L.) Sch. Bip. Grassland species recorded at Irish sites: *Plantago lanceolata* L. Freshwater/moorland species recorded at Irish sites: *Cladium mariscus* (L.) Pohl, *Menyanthes trifoliata* L., *Ranunculus flammula* L.

4. Discussion

4.1. Introduction

In broad terms, rectangular houses, 'pits' and mortuary monuments dominate the archaeological record of the Irish Neolithic. EN II, from 3750 cal BC, saw widespread construction of a variety of site-types. However, there are fewer indications of activity for the Middle and Late Neolithic, when settlement evidence appears more ephemeral. In particular, there is a marked lull in settlement activity during MN II, from around 3400 cal BC to just after 3000 cal BC, when the archaeological record is almost completely dominated by burials of the developed passage tomb tradition. This pattern can be expressed visually by examining the frequency distribution of radiocarbon dates for different site-types (Fig. 19), using a moving 50-year average of the frequency of dates whose modal calibrated date falls before 2500 cal BC. Rectangular houses and 'possible houses' are grouped together, with a clear EN II 'house horizon', and elevated activity in the Late Neolithic. 'Pit' use fluctuates during the final centuries of the Mesolithic, peaks with the rectangular houses, and almost ceases c. 3300–3000 cal BC.

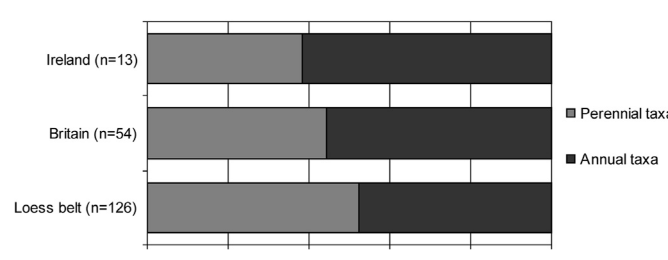

Fig. 14. Proportions of annual and perennial potential arable weed taxa from Neolithic Ireland, Britain and central Europe. Analysis of charred seeds identified to species level; trees/shrubs excluded. Data source for non-Irish results: Bogaard and Jones (2007; in press). Annual taxa from Irish sites: *Avena* spp., *Galium aparine* L., *Hyoscyamus niger* L., *Lapsana communis* L., *Lolium temulentum* L., *Polygonum aviculare* L., *Raphanus raphanistrum* L., *Tripleurospermum inodorum* (L.) Sch. Bip. Perennial taxa from Irish sites: *Cladium mariscus* (L.) Pohl, *Menyanthes trifoliata* L., *Plantago lanceolata* L., *Ranunculus flammula* L., *Rumex acetosella* L.

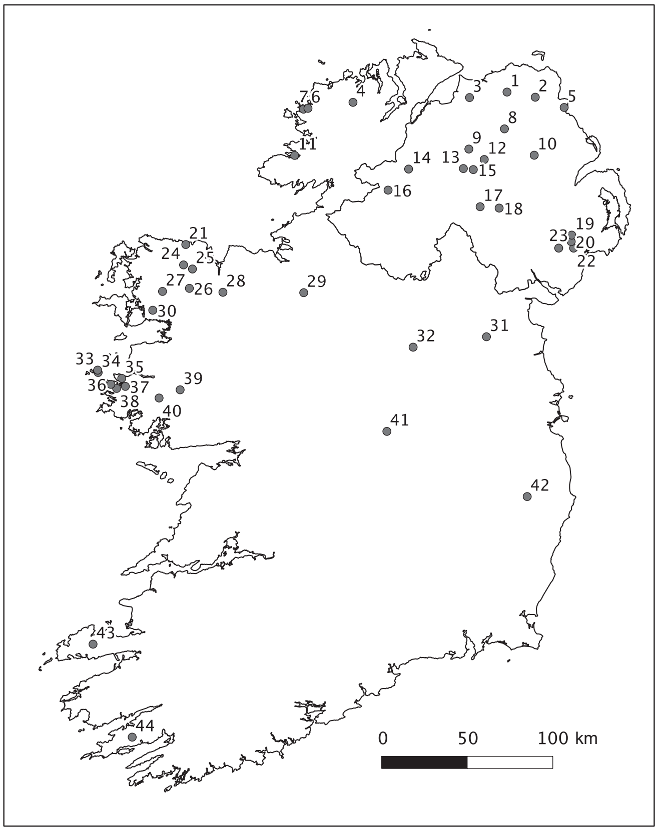

Fig. 15. Distribution of Irish pollen sites used. List of sites: 1. Garry Bog, 2. Altnahinch, 3. Gortcorbies Bog, 4. Lough Nadourcan, 5. Lough na Trosk, 6. Lough Nabradden, 7. Altar Lough, 8. Fallahogy, 9. Crockbrack, 10. Sluggan Moss, 11. Lough Mullaghlahan, 12. Slieve Gallion, 13. Beaghmore, 14. Lough Catherine IV, 15. Ballynagilly, 16. Meenadoan, 17. Killymaddy Lough, 18. Weir's Lough, 19. Slieve Croob, 20. Carrivmoragh, 21. Céide Fields (Glenulra), 22. Slievenaslat, 23. Lackan I, 24. Croaghaun East, 25. Garrynagran, 26. Lough Clevala, 27. Corslieve Lough, 28. Lough Doo, 29. Carrowkeel, 30. Lough Anaffrin, 31. Moynagh Lough, 32. Derragh Bog, 33. Lough Gowlanagower, 34. Church Lough, 35. Derryinver, 36. Lough Sheeauns, 37. Connemara National Park, 38. Crocknaraw, 39. Ballydoo Bog, 40. Lough Maumeen, 41. Clara Bog, 42. Arts Lough, 43. Lough Camclaun, 44. Cashelkeelty.

The low archaeological visibility of less structured features such as ephemeral pits and spreads, which characterise the domestic archaeology of the period (Grogan, 2002, 517), may partially explain this pattern. With limited post-excavation resources, archaeologists have chosen to date more obvious features such as rectangular houses. However, some 37% of known Neolithic 'pit/posthole/spread' sites have been ^{14}C dated. Therefore, it could be argued that this is a reasonably representative sample and the frequency of pit use though time is a possible indicator of the fluctuating levels of human activity over the centuries (cf. Shennan and Edinborough, 2006). Behavioural and taphonomic factors must also influence the pattern to a degree.

Table 2
^{14}C determinations from Caw. Do. Derry (calibrated in OxCal 4.1).

Context	Material	Lab no.	^{14}C BP	±	95% cal B C	
N wall slot	Charcoal	UB-4979	4989	39	3939	3661
Internal pit 60	*Triticum* cf. *dicoccum*	UBA-14651	4907	39	3767	3640
Internal pit 60	*Triticum* cf. *dicoccum*	UBA-14652	4861	39	3711	3531
Posthole 74	*Triticum* cf. *dicoccum*	UBA-14653	4920	39	3775	3643
Posthole 74	*Triticum* cf. *dicoccum*	UBA-14654	4880	39	3762	3539
Central hearth	*Triticum* cf. *dicoccum*	UBA-14655	4880	39	3762	3539
Central hearth	Unid. cereal grain	UBA-14656	4950	39	3892	3649
Posthole	*Hordeum*	UBA-14657	4941	43	3892	3643
Posthole	*Hordeum*	UBA-14658	4818	26	3653	3528

Environmental indicators suggest that conditions were drier after 4100 cal BC than they had been during previous centuries. A rise in Irish bog-oak populations (Fig. 20, centre graph) around the large inland Lough Neagh suggests a lowering in water levels, conditions supported by evidence from other bog-oak sites in the region (Barratt et al., submitted). The balance of evidence suggests that Britain and Fennoscandia also experienced drier, warmer conditions, as do several other North Atlantic marine proxies (Barnekow and Sandgren, 2001; Farmer et al. 2008; Andersson et al. 2010; Heikkilä et al. 2010; Moir et al. 2010), although some available records suffer from problems of chronology. It is particularly striking how closely trends in the Ulster bog-oak and Ulster archaeological summed probability radiocarbon data track each other during EN I, EN II and MN I (Fig. 20, centre graph), especially the sharp changes in gradient at the EN II boundary, 3600 cal BC. The peak in the probability curve during EN I and EN II is likely exaggerated by the shape of the Intcal09 calibration curve (cf. Williams, 2012), leading to higher probabilities being computed in this period, and the considerable research bias towards early Neolithic archaeology. This is partly due to the high visibility of these sites in the archaeological record, and partly due to the continuing interest among researchers in this pivotal epoch. A mixture of charcoal, bone and seed ^{14}C dates had to be used in this analysis to gain the recommended volume of ^{14}C dates for the summed probability analyses (cf. Williams, 2012). This is likely to have caused an 'old wood' effect on the shape of the probability curve, especially for the EN I. A preliminary comparison of summed probability distributions between short-lived and bone dates, versus charcoal dates, shows that this 'smearing' of dates is particularly obvious during EN I compared with later periods, when there is far greater overlap between charcoal and short-lived/bone probability curves (McLaughlin et al., in preparation). One possible explanation for this pattern is that a proliferation of older wood may have been available on the forest floor compared with later periods, which was preferentially collected and burnt during EN II (and possibly in EN I); subsequently, such older wood might have been less readily available. This pattern is worth exploring further as it might have a number of interesting implications for population sizes in the Neolithic or the intensity of wood resource usage at this time. Palaeoecologically, we know that many of these Holocene woodlands contained a proliferation of dead wood (Whitehouse, 2006); such material might have been the most easily available fuel in the earlier stages of the Neolithic.

Despite these issues, the summed probability data usefully allow us to examine the broad pattern of change at this time and the data track the findings of the other lines of evidence from the project. Thus, we know that there are high levels of archaeological activity in Ireland between 3750 and 3500 cal BC – obtained from the targeted dated settlement sites, archaeobotanical assemblages and palaeoenvironmental sequences examined as part of the project – and that there are declining levels of activity between 3500 and 3300 cal BC – obtained from the same assemblages – even without considering the probability data. We believe this data *must* therefore hint at rapidly changing population levels and/or a widespread change in behaviour. The vegetational changes that occur at this time suggest re-afforestation and lend further support to the degradation of the settlement signal. Thus, despite some of the noted difficulties associated with the use of summed radiocarbon dates (Michczyńska and Pazdur, 2004; Surovell et al., 2009; Williams, 2012), they lend support to the evidence we have assembled and examined, using different approaches and analyses, from both the archaeological and palaeoenvironmental record from Neolithic Ireland.

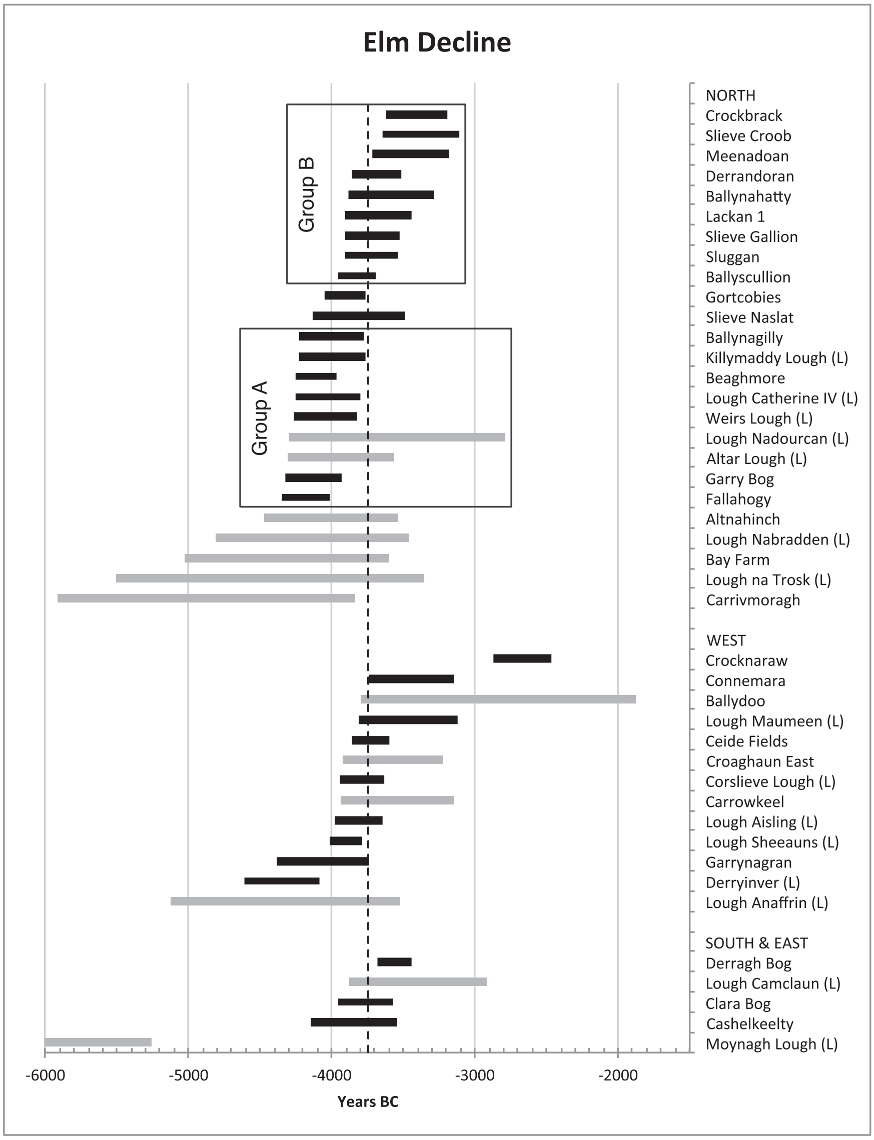

Fig. 16. Date ranges of the Start of 'Elm Decline' 1, from the North, West and South & East of Ireland. Date ranges >700 yrs = grey line; <700 yrs = black line. Dashed line shows start of Neolithic as defined by our work. Lough sites are identified by (L).

Certainly, early agriculture in Ireland seems to have been initiated at a time of environmentally favourable conditions, especially between 4000 and 3600 cal BC, whilst changes in the nature of archaeological settlement (3400–3100 cal BC) occurred during a period of declining bog oak populations, themselves indicating substantial changes in wetland environments that affected bog oak germination (Barratt et al., submitted). Jones et al. (2012, 3236) have recently argued that the period of warmer, drier conditions around 4000 cal BC may have been critical in facilitating the spread of agriculture across northern Europe by extending the growing season of crops in spring. Whether all of the changes noted in the records are the consequences of climatic or social changes, of course, is a complex matter. We examine the nature of our records in greater detail in the sections below.

4.2. Early Neolithic: EN I (4000–3750 cal BC)

Our dating programme provides no unambiguous evidence for the presence of arable farming during EN I. There is only one dated cereal grain for this period, 3942–3707 cal BC from Tankardstown South, Co. Limerick; however, its date range extends into EN II, and Bayesian modelling emphasises this attribution, particularly in the light of the other dating results from the site, as well as those of the wider corpus. Careful evaluation of EN I archaeological dates suggests these should be treated with considerable caution as they are largely based on charcoal, sometimes in uncertain association with the material or structure of interest (e.g., Carrowmore; Burenhult, 1984). The early cattle bone from Ferriter's Cove remains an enigma, as are the early charcoal dates from Magheraboy. EN I also marks the start of a rise in the summed cumulative probability radiocarbon record (Fig. 20). This increase occurs just prior to the EN II boundary, likely the product of the 'smearing' of archaeological dates across this boundary due to the mixture of charcoal, bone and seed ^{14}C dates used in this analysis. On the other hand, in addition to the few early domestic animal bone dates such as Ferriter's Cove, there are a small number of dates on human bone preceding 3750 cal BC, including calcined bone from the Baltinglass passage tomb, Co. Wicklow (this project) and Tully court tomb, Co.

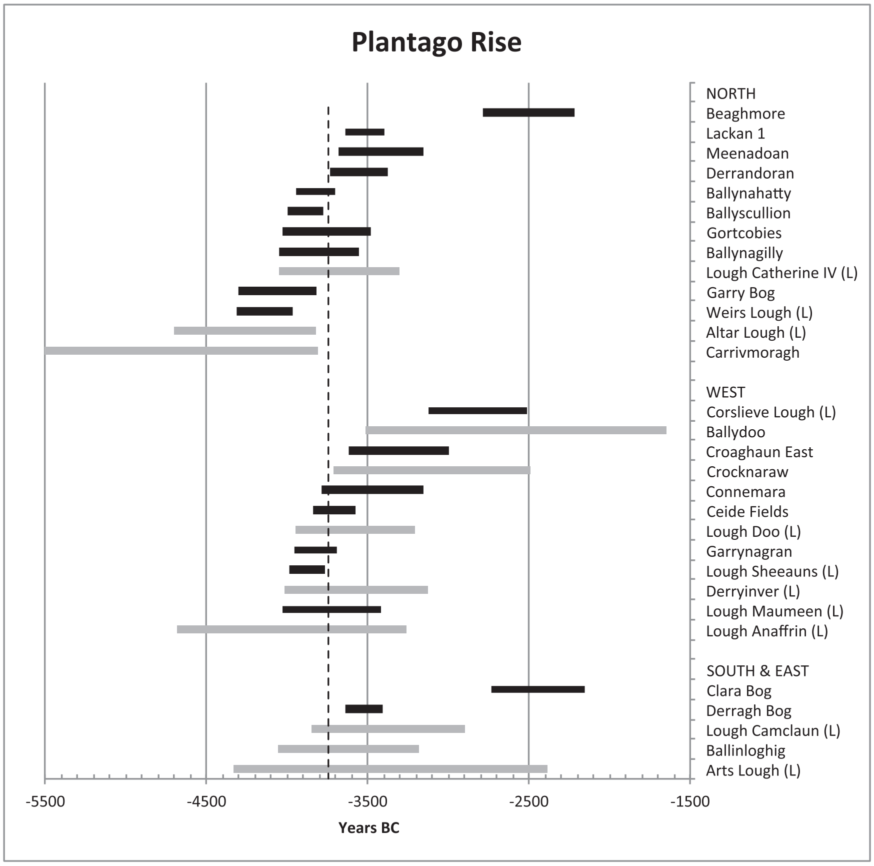

Fig. 17. Start of rise in presence of *Plantago lanceolata* L. ('Plantago Rise'), from the North, West and South & East of Ireland. Dates ranges as per Fig. 16. Dashed line shows start of Neolithic as defined by our work.

Fermanagh (Schulting et al. 2011). As individual site determinations also yield later dates, the early part of their calibrated ranges tends to be excluded in Bayesian models, leaving their interpretation open to debate. More difficult to discount in this way are a number of new early AMS results on unburnt human bone from Poulnabrone portal tomb, Co. Clare, supporting the single early result obtained in the original dating series (Lynch and Ó Donnabháin, 1994; Schulting, submitted). Burial activity here is modelled as commencing some 50–100 years before 3750 cal BC, providing seemingly good evidence for a Neolithic presence preceding the 'house horizon' of EN II.

EN I includes the start of the Elm Decline 1, which was not synchronous across Ireland, with two possible groups of dates in the north of Ireland where the data are most abundant, an earlier one (A) (start *4350–4220 cal BC*) and a later one (B) (start *3950–3620 cal BC*). In some cases, the age-range for the Elm Decline extends until 3000 cal BC (Fig. 16). This is in contrast to the findings of Parker et al. (2002, 9) who suggest that the onset of the Elm Decline was a catastrophic event starting within a 36-year window. Group A sites may be chronologically problematic, as previously discussed. Group B and western sites show that the Elm Decline is coincidental with early agriculture, covering both EN I-II, but also extending into MN I-II; the current imprecision of this event resists identifying any potential causal relationships. There appears to be an earlier start to the Elm Decline in the north of Ireland compared with the west. Although the calibrated date ranges do overlap to varying degrees, the 'event' straddles nearly one thousand years. There are also sites that clearly do not overlap (e.g. Fallahogy, Co. Derry, Beaghmore, Co. Tyrone and Garry Bog, Co. Antrim, are separate from Sluggan Bog, Co. Antrim). This strongly indicates (i) uncertainty as to the synchroneity of this event, aside from the fact that the majority of dates fall 4000–3000 cal BC, and that (ii) there is considerable variation in its dating both at individual sites and regionally. Based on this work, we urge caution in the use of the Elm Decline 1 as a pollen-stratigraphic marker in the absence of other supporting dating (e.g. ^{14}C dates).

4.3. Early Neolithic: EN II (3750–3600 cal BC)

EN II, from 3750 cal BC, is a period of considerable 'boom' in the archaeological record. Neolithic settlement is marked by the 'house horizon,' *3720–3620 cal BC* (Table 3), lasting up to a century (*40–100 years*). The cumulative radiocarbon probability curve (Figs. 19 and 20), reaches its peak within this period. Overlapping with this phase, but persisting longer, is the 'pit/post-hole complex', from *3710–3460 cal BC* (Fig. 19). The end date for these sites may well extend into the earlier part of the 3rd millennium, but it is hard to evaluate this at present due to a paucity of dates.

The 'house horizon' also coincides with the current radiocarbon dating evidence for the initial use of court tombs in Ireland (Table 3), with use continuing into the Middle Neolithic (Schulting et al. 2011). This, in turn, has much in common with the modelled initial use of mortuary monuments in southern Britain (Bayliss and Whittle, 2007b), suggesting that the late 38th and early 37th centuries cal BC were a period of intense activity in the Neolithic of both Ireland and Britain. This fits well with Cooney et al.'s (2011, 663) re-evaluation for the appearance of the Neolithic in Ireland, based on Bayesian modelling. Their Model 2 places this at *3750–3680 cal BC* and Model 3 at *3850–3740 cal BC*. Our proposed EN II (*3750–3600 cal BC*) is in good agreement with Model 2, but there is

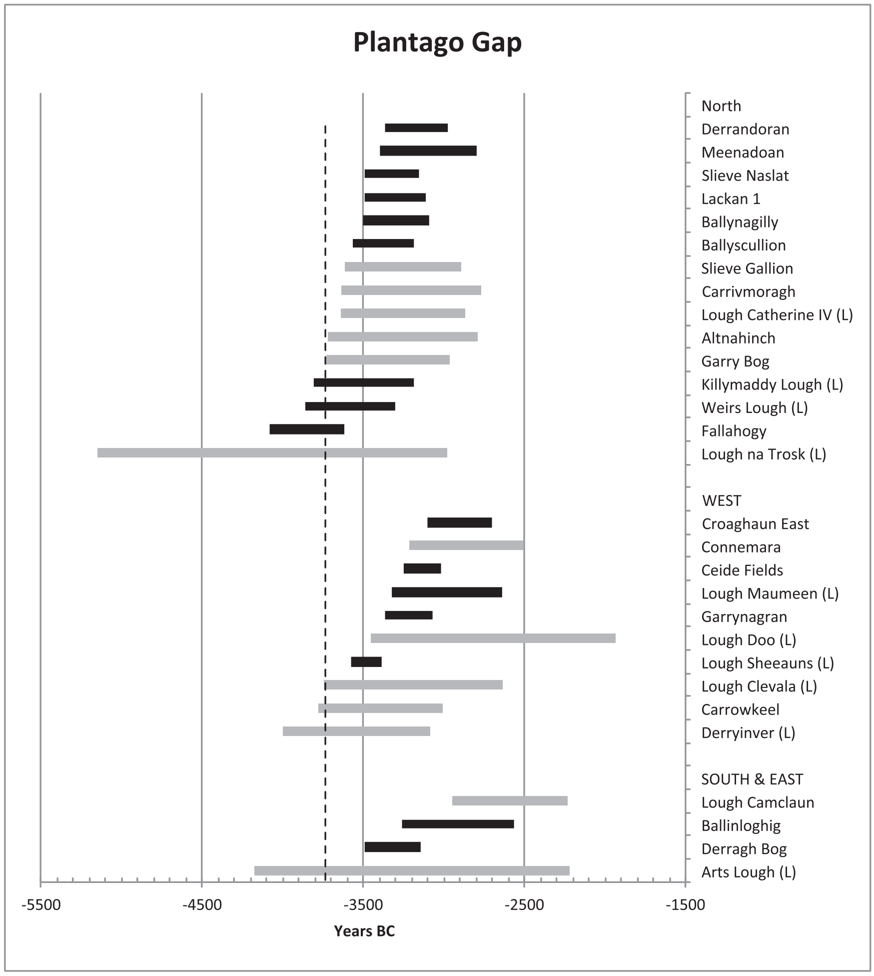

Fig. 18. Date ranges for the start of the '*Plantago* Gap' from the North, West and South & East of Ireland. Dates ranges as per Fig. 16. Dashed line shows start of Neolithic as defined by our work.

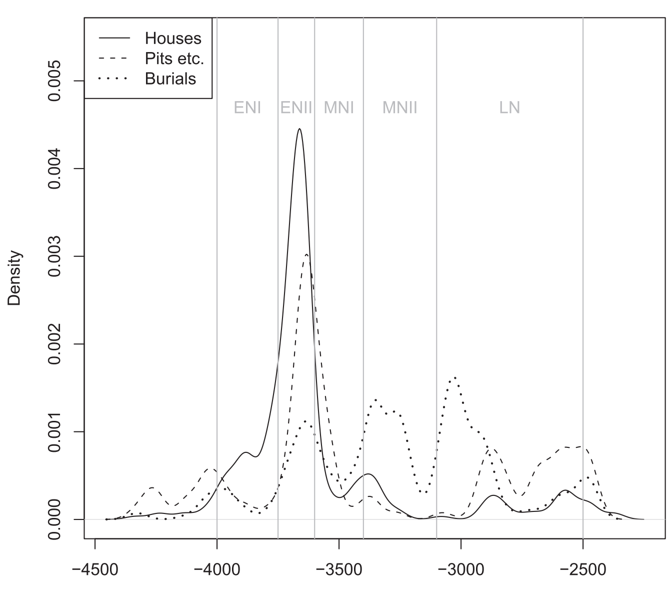

Fig. 19. Frequency distribution of radiocarbon dates for Irish Neolithic rectangular houses, pits and burials (n = 871 ^{14}C dates: 317 from houses, 212 from pits and 342 from burials, based on charcoal, short-lived seeds and bone samples).

sufficient evidence to suggest that elements of the Neolithic – domesticated animals and mortuary monuments (e.g., Poulnabrone) – were present earlier than this, and so supporting Model 3. In either case, the Irish Neolithic seems to have started slightly later than in England and Scotland (Table 3).

It is worth comparing the Irish 'house horizon' with the larger Scottish timber halls, of which there are now four excavated examples (Fairweather and Ralston, 1993; Barclay et al. 2002; Kirby, 2011; Murray et al. 2009). These have been interpreted as communal residences that may have been used in the very early stages of occupation, before the 'budding off' and establishment of individual households (Sheridan, 2013). In the three Scottish cases for which published dates are available, the halls appear to be consistently earlier than the smaller rectangular houses found in Ireland, by as much as a century or so (Table 3). Interestingly, their use also appears to have ended in the mid-4th millennium BC. These records contrast with much of England and Wales, where domestic architecture remains comparatively rare. Preliminary indications are that they may be as early as the Scottish halls (Kenney, 2008; Bayliss et al. 2011). The Irish Neolithic, however, remains distinctive in the larger number of rectangular houses that have been discovered, their smaller size, as well as their occasional clustering into groups of three to six or seven, more or less contemporary structures (Grogan, 2004; Smyth, 2006, 2010).

The earliest evidence for cereals dates to around 3750 cal BC or slightly earlier, depending on one's view of statistical outliers.

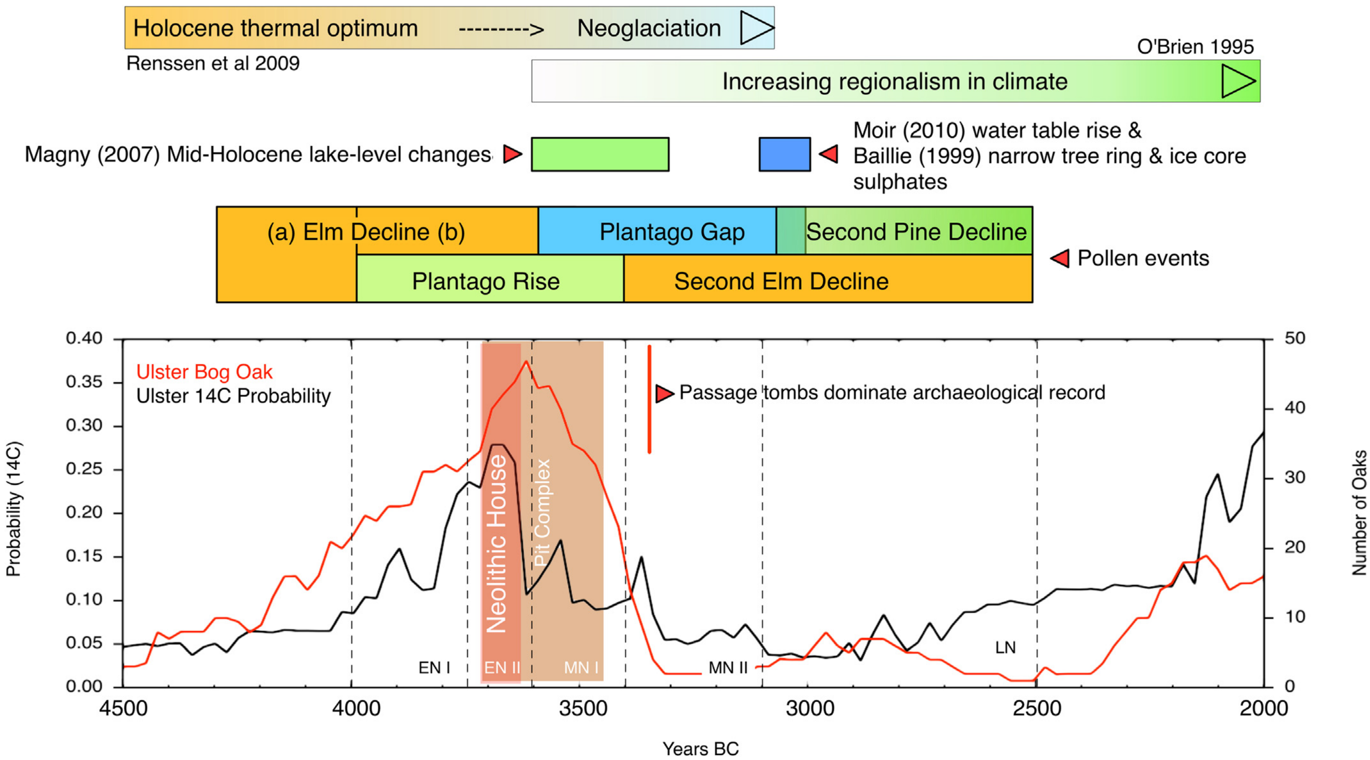

Fig. 20. Summary of archaeological, environmental and climate events during the Neolithic in Ireland. The central graph shows the cumulative archaeological radiocarbon record for Ulster (n = 740 ^{14}C dates) generated by us, overlain with a bog-oak population record, from Ballymacombs More, in the Bann Valley, Co. Antrim (Barratt, 2007; Barratt et al., submitted). The bottom graph shows North Atlantic marine ice rafted debris record of Bond et al. (2001). Boxes at the top of the diagram show the duration of some of the pollen events dated, together with age ranges of several regional climate records.

Cereals are clearly being consumed at many types of sites during this period, with emmer wheat dominant, but there is also significant evidence for barley (naked and hulled), as well as occasional evidence for einkorn wheat, naked wheat and flax. The ubiquity of cereals suggests that they were available to many different communities. The evidence for einkorn wheat is poor (McClatchie et al. 2014); although introduced during the Early Neolithic, its cultivation did not take hold and spread to any great extent, with emmer being the preferred hulled wheat at this time. The low uptake of einkorn seems to have been a wider phenomenon, being apparent not just in Ireland, but also Britain and possibly northern France (McClatchie et al. 2014).

While cereals were certainly significant, Neolithic communities were also making use of locally available wild resources, which would have thrived along the edges of cleared ground (Groenman van Waateringe, 1983). Most archaeobotanical assemblages contained a range of gathered foods, especially hazelnuts but also apple and bramble. The range of wild plant taxa available to Neolithic communities can be seen at the EN II burnt mounds of Clowanstown, Co. Meath (Mossop and Mossop, 2009). Waterlogged conditions here preserved a range of wild plants that are likely to have been growing in the local landscape, some of which may have been gathered as leafy greens, in addition to hazelnuts and fruit. The regular occurrence of potential wild foodstuffs in the archaeological record, as well as cereals, indicates a diet that made use of many different types of plant resources. The presence of late Mesolithic and early Neolithic occupation at Clowanstown, albeit with an intervening hiatus of a few hundred years, in common with the waterlogged platform structure at Lough Kinale, Co. Longford (Fredengren et al. 2010) indicates re-use of Mesolithic locations either by incoming early farmers or the descendants of the previous occupants of these sites. The inhabitants of these sites were using domesticated resources. Clowanstown and Kinale present evidence of stratified Mesolithic deposits underlying early Neolithic activity, something that is not seen with the scattered Mesolithic finds that can be found in small numbers at other early Neolithic sites, including the house sites. Sheridan (2013) suggests that Lough Kinale may provide evidence for acculturation of existing populations; Clowanstown might fall within a similar category. It is perhaps rather early to be sure how these sites fit into the overall scheme of the EN II, not least as they are not yet fully published, but they would appear archaeologically unusual in the context of the early house phenomenon.

Like farmers elsewhere in Neolithic north-west Europe, early farmers in Ireland were not engaged in shifting cultivation, but rather created a sense of place by practicing longer-term, fixed-plot agriculture. It had been previously assumed that early farmers were engaged in shifting cultivation, progressing to more intensive practices during the Bronze Age (for example, Barrett, 1994, 144–

Table 3
Bayesian modelled start and end date ranges (cal BC). Scottish sites have been remodelled here using charcoal outlier analysis in OxCal 4.1

	Start (95%)		End (95%)		Source
Irish EN houses	3720	3680	3640	3620	This publication
Irish MN pit complexes	3710	3655	3515	3460	This publication
Tullahedy Neolithic	3675	3645	3510	3460	Schulting 2012
Irish court tombs	3715	3550			Schulting et al., 2012
Balbridie, Aberdeenshire	3955	3655	3765	3495	Fairweather and Ralston 1993
Claish, Stirling	3780	3655	3695	3620	Barclay et al. 2002
Crathes, Aberdeenshire	3800	3715	3765	3685	Marshall 2009

49). The evidence from central Europe, Britain and now Ireland, however (Figs. 13–14), indicates that shifting cultivation was not taking place, as plants associated with disturbed ground dominate the arable weed assemblages, and annuals are common. This suggests that, instead, the earliest farmers were carrying out more intensive practices in these regions. Management of plots may have included practices such as manuring to maintain fertility (cf. Bogaard et al. 2007; Fraser et al. 2011).

Clearance and opening of the forest canopy did not occur in any substantive way until EN II, with increased levels of *Plantago lanceolata* pollen recorded from 4000–3500 cal BC onwards – the resolution of the data makes it hard to be more specific; vegetation throughout the island had probably been affected by 3400 cal BC. Whilst early agriculture left a strong human signature in some pollen records (e.g. Céide Fields, Co. Mayo), many records do not give an impression that agriculture played a substantive role or that it impacted the wider landscape in a major way in these early phases. How do we reconcile this with the evidence from the plant macrofossil record? Partially, this may be because there is a mismatch between the location of pollen study sites and archaeobotanical sites, but more likely the answer lies with how crops were being cultivated. These were likely cultivated on small, permanent plots, best described as intensive garden agriculture (Bogaard, 2004). Such plots are unlikely to have been extensive and thus may have been poorly visible palynologically, due to the combined effects of low cultivar pollen production and filtration, where tree pollen may 'swamp' assemblages (Sugita et al. 1999; Bunting et al. 2004; Bunting, 2008). Landscape usage by agriculturalists was likely not uniform, creating instead a spatially heterogeneous landscape of varying intensity and use depending upon local circumstances and population densities.

EN II sites (Fig. 10) are clustered in the north and east of the country, with very few from the centre and west; this could be seen as the product of Ireland's recent infrastructural developments. On the other hand, recent roadworks across the Irish Midlands have failed to produce equivalent archaeology (McLaughlin et al., in preparation). It is possible that greater regional heterogeneity will become more evident (e.g. due to differing soils and growing conditions) as further sites are examined; careful examination of different regions of Scotland has revealed such a pattern, showing diverse regional resource strategies (Bishop et al. 2009). It is noticeable that many of these early Irish sites are located along major river systems (Fig. 10); this may be the product of the bias towards the eastern part of the country where development has taken place or may reflect the mechanism by which people moved around the landscape and their preferred places of settlement. Several researchers (e.g. Davison et al. 2006; Rowley-Conwy, 2011) have emphasized the role of waterways in the rapid spread of the Neolithic across Europe.

4.4. Middle Neolithic: MN I (3600–3400 cal BC)

The boundary of EN II-MN I, at around 3600 cal BC, offers the most thought-provoking transition *within* the Neolithic, with changes in the environmental and archaeological records. The bog-oak record starts to decline at the transition to MN I, at 3620 BC, with the steepest decline at 3500 BC (Fig. 20; central graph) and this is interpreted as an increase in climatic-derived wetness in Ireland (Barratt et al., submitted). A clear phase of high bog surface wetness indicative of wet and cool conditions has recently been identified in central Ireland, from Derragh Bog, Co. Longford at the same time (Langdon et al. 2012). Other palaeoenvironmental data suggest that the period from 3600 cal BC appears to have been climatically unsettled and increasingly regionalized (e.g. O'Brien et al. 1995). Increasing wetness is shown around 3500 BC in German bog pine records (Eckstein et al. 2011), whilst Magny et al. (2006) provide well-dated evidence for climatic reversals in European lake sequences. Although regional records, these fit well with more precisely dated data from northern Europe and Ireland.

The rectangular house tradition ends by *3720–3620 cal BC*, whilst complexes of pits, post-holes and spreads dominate the settlement archaeology, continuing to be present until at least *3515–3460 cal BC*. The nature of the archaeological record suggests lower levels of activity in MN I relative to those seen in EN II, due either to an actual reduction in population or to a widespread change in depositional practices: distinguishing these very different options is far from straightforward. Many of these sites remain undated and require further investigation, but usually include occupation debris and may represent the remains of more temporary, mobile settlement patterns. Smyth (2013, 313) has, however, recently argued that the construction of houses does not end during this period; rather, that there may have been a shift in methods of construction. She suggests that the house structures and associated palisaded enclosure at Tullaheady, Co. Tipperary, do not belong to the same tradition as the EN II houses on the basis of chronology, architectural features and ceramic styles (Smyth, 2013, 311) and furthermore, that several other undated sites might belong to this period (e.g. Lough Gur, Co. Limerick), indicating that some groups, at least, may have chosen to live in clusters of several households, in enclosed settlements. The palisaded enclosure site at Thornhill, Co. Antrim (Logue, 2003), containing a number of house structures, along with evidence for burning of the palisade may conceivably belong to this period, but regrettably remains undated. However, Bayesian modelling of the dates for Tullahedy suggests that its houses do fall within the EN II house horizon, albeit towards its end (Schulting, 2011). Whether the construction of rectangular houses continued into MN I therefore remains uncertain. The final phases of causewayed enclosure sites such as Donegore Hill, Co. Antrim, fall within MN II, with an estimated end date of *3590–3430 cal BC* (Cooney et al., 2011), indicating that these sites continued in usage until the MN I. It is clear, therefore, that although 'pit complexes' dominate the settlement archaeology that there may have been more diverse settlement types during this period, but that these require further chronological exploration and that several key sites need further study.

The funerary landscape is complex during this period. While it is unclear whether they were still being constructed, at least some portal and court tombs continued in use while, simultaneously, Linkardstown cists (Brindley and Lanting, 1990, 1992) and passage tombs both appear. There is evidence for early passage tombs (ENII – MNI) at Baltinglass, Co. Wicklow and Carrowmore, Co. Sligo, the former based on dates on cremated human bone fragments obtained through the present project, and the latter on new ^{14}C dates from calcined bone pin fragments from two of the monuments (3 and 55A) (Bergh and Hensey, 2013), suggesting that the initial construction of simple passage tombs in Britain and Ireland was earlier than the more developed monuments exemplified by Knowth and Newgrange (Sheridan, 2003; Schulting et al, forthcoming). Middle Neolithic deposition occurred at the court tombs at Annaghmare, Co. Armagh and Parknabinnia, Co. Clare (Schulting et al. 2011) and the portal tomb at Poulnabrone, Co. Clare (Lynch and Ó Donnabháin, 1994).

The nature of the archaeobotanical record at this time (Fig. 11) appears to largely remain the same as during EN II, but the number of sites ($n = 10$) is rather limited. In contrast, in landscape terms, the MN I period overlaps the start of the '*Plantago* Gap' (Fig. 18; c. *3500–3000 cal BC)*, marking the beginning of less intensive use of the landscape and possible re-afforestation, which is often accompanied by declines in other non-arboreal indicators and increases in shrubs and trees (e.g. Glenura Basin, Céide fields, Co. Mayo;

Ballynagilly, Co. Tyrone). O'Connell and Molloy (2001) noted this re-afforestation in western Irish sites, but it is now clear that this was a spatially extensive horizon, occurring in the north, west and south of the island. In the north, this phase starts from c. 3500 cal BC, and a few hundred years later in the west. Chronological resolution is such that we cannot define the overall period further beyond this 500-year time window; moreover, the phenomenon is clearly not synchronous all over the country.

4.5. Middle Neolithic: MNII (3400–3100 cal BC)

The bog oak record continues to suggest wetter conditions at the start of MN II, reaching minimum levels by 3300 BC; by 3100 BC, however, bog oak populations start to recover in earnest. Evidence from sub-fossil pines in Ireland and Scotland (Moir et al. 2010) suggest that conditions were less wet between 3200–3000 BC i.e. during the latter stages of MN II.

From 3400 cal BC, there is a reduction in archaeobotanical data. The presence of cereals at a much smaller proportion of MN II–LN sites may not necessarily imply that cereals were less important, since there are fewer dated assemblages from this time, reflecting less intensive sampling strategies due to a significantly reduced number of 'domestic' structures. After 3400 cal BC, barley occurs on slightly more sites that wheat, but sample size is very small ($n = 4$), and it is therefore difficult to ascertain if there is any actual change in the significance of either wheat or barley. There is an increase in fruit remains at MN II–LN sites compared with earlier periods, accompanied by a decrease in hazelnut remains, suggesting variability in the use of wild, gathered foods at this time. It is important to appreciate the limited number of Irish archaeobotanical sites available for this time period ($n = 11$); this pattern may be an artefact of the limited dataset and mean that our interpretations of these data must be treated with some caution and will require further exploration when new data become available.

Between 3300 and 3000 cal BC (Figs. 19 and 20), the sparse radiocarbon-dated settlement data suggest there is a lull in settlement activity, with an apparent hiatus in pit deposition, while the dates associated with the few rectangular houses that appear do not relate to the construction or primary occupation phases. In part, this may be because fewer sites of this period have been ^{14}C dated and sites are much more ephemeral archaeologically, but possibly this is a real pattern and may be indicative of a decline in population and/or changes in activities. Despite the limited evidence for day-to-day activities, this period coincides with a peak in passage tomb construction (Schulting et al., forthcoming) that further adds to the complexity in our understanding of these settlement changes. These contrasts in the nature of the archaeological record are intriguing and merit further attention. Although it may be tempting to interpret the changes in settlement patterns as representing increasing mobility by communities, the construction of elaborate passage tombs in prominent locales emphasises the importance of place and permanence within social and ritual contexts.

The '*Plantago* Gap' is well represented during the MN II and seems connected to potential changes in agricultural activities. The '*Plantago* Gap' has parallels with several other palaeoecological records from this period and may be part of a wider pattern. A recent re-evaluation of the British Holocene fossil beetle evidence (Whitehouse and Smith, 2010) showed that clearance activity during the early Neolithic was followed by a re-afforestation phase, commencing c. 3500 cal BC. Some decades ago Whittle (1978) and Bradley (1978) noted that the earlier British Neolithic was followed by a period of woodland regeneration and decline in agricultural activity. This was originally criticized on palynological and temporal grounds (Edwards, 1979), but it would seem that our study provides support for a period of re-afforestation c. 3500–3000, which was widespread across Ireland and may have coincided with a similar event in Britain (Woodbridge et al., 2014). Detailed chronological analyses of the British pollen data are needed to explore this further.

Bishop et al. (2009) note the increasing use of wild plants in Scotland around a similar time, c. 3300 cal BC (our MN II), alongside a significant increase in the utilization of barley, a crop more tolerant of cooler, wetter conditions, and a decrease in wheat use in southern and north-east Scotland. They suggest this may be due to responses to increased risk of crop failure and worsening growing conditions for wheat during the later 4th millennium BC. It is tempting to interpret the reduction in Irish evidence for cereals in a similar manner, although it should be noted that a reduction in the recovery of hazelnut remains accompanies the decrease in cereals. The Scottish dataset has not been subjected to the same Bayesian analyses as the Irish data, which may further resolve this pattern. Researchers have stressed the importance of wild plants in Neolithic Britain (Moffett et al. 1989; but see Jones, 2000), especially hazelnuts, as well as various fruits including wild crab apple, sloe, blackberry/rasberry, hawthorn and tubers (Robinson, 2000) and that wild foods are frequently better represented than cereal grains and crop waste (Stevens and Fuller, 2012). Much of this plant evidence (cf. Jones and Rowley-Conwy, 2007) has not been sufficiently resolved chronologically to examine temporal patterns in detail. New research by Stevens and Fuller (2012) based on probability distributions of British cereal and hazelnut radiocarbon dates suggest that there is evidence for an initial decline of cereal cultivation around c. 3650–3600 cal BC, followed by a sharper decline at 3350 cal BC when cereal cultivation may even have been potentially abandoned. It is worth noting that this contrasts with our data, where we see a decrease in both hazelnut alongside cereals during this latter period, whilst in other areas such as the Orkneys, Scotland, evidence for cereal cultivation continues through this period (e.g. Braes of Ha'Breck; Thomas & Lee, unpublished data).

It is clear from the palaeoenvironmental, palynological, settlement and archaeobotanical data that the period c. 3600–3000 cal BC was one of considerable environmental, landscape, settlement and economic change. The apparent geographic spread and extent of some of the changes evident in the various records – especially the archaeobotanical and palynological - could be related to the unsettled nature of climate over the period c. 3600–3000 cal BC. Crops are especially vulnerable to short-term climatic variability and extreme weather events (Dark and Gent, 2001). We know relatively little about the needs of ancient crops, the genotypes available in prehistory and how these may have affected a crop's ability to withstand climatic fluctuations (Brown et al. 2008). Genetic work suggests that adaptations occurred during the spread of cereal crops which allowed species to adapt to the wetter, cooler climates of central Europe (Jones et al. 2008, 2012), and perhaps similar changes were required to adapt to the oceanic fringes. Newly arrived crop varieties from adjoining continental areas of Europe may have been particularly vulnerable to climatic events, particularly within the context of the rapid transition to agriculture across Britain and Ireland, since the genetic changes required to adapt to the wetter, more oceanic climatic conditions across these islands may have still been evolving.

Perhaps some of the evidence is also associated with human adaptation and resilience in the face of changing conditions during a period of uncertainty. There is a suggestion in the data that the climatic event recorded in the Irish bog oaks (Barratt et al., submitted) and bog surface wetness records (Langdon et al. 2012) occurs 100–200 years or so before we see any registration of change in the archaeological record. It is probable that the different

levels of dating precision associated with dendrochronology and ^{14}C dating in part create this, but there may also be some level of 'inertia' within the archaeological record: communities may have been slow at first to adapt to changing conditions, but the unreliability of crops may have forced changes in emphasis following the early period of expansion. Unfortunately, the chronological resolution of much of the material remains insufficiently well-resolved to address this question. Alternatively, are we seeing a period of adjustment in agricultural communities once the 'honeymoon' period of early agriculture on a wet Atlantic island had run its course? Dark and Gent (2001, 71) used just such a term when considering the effects of soil impoverishment, pests and diseases on early agriculture in north-west Europe. In areas with limited fertility, such as the thin soils of the west coast of Ireland, arable agriculture may indeed have been of limited duration. There is also the possibility that what we are seeing are a series of environmental events that are, in effect, being conflated. This is certainly hinted at in both the British data (Stevens and Fuller, 2012) and our data. Further analyses will be needed to examine and tease these out more fully.

It is perhaps significant that records from elsewhere across Europe suggest that this period was of some uncertainty; Schibler and Jacomet (2010) report the increased hunting of wild animals in alpine regions between 3200 and 3000 BC (dendro dated), which they argue may have been a strategy developed for dealing with short-term climatic fluctuations. Likewise, Tallavaara and Seppä (2012) report an abrupt decline in hunter–gatherer populations in Fennoscandia at c. 3500–3000 cal BC which they attribute to boreal forest ecosystem changes, associated decreasing animal productivity and biomass and decreasing food availability for hunter–gatherers. They argue that late-Holocene climate cooling caused this. Likewise, Hinz et al. (2012) argue for a population decline c. 3350–3100 cal BC at Funnel Beaker sites in Northern Central Europe and Southern Scandinavia based on probability ^{14}C dates and a pollen-based proxy for human impact.

It is clear that the second half of the 4th millennium is a period of considerable interest, in need of much more research attention. It is worth stressing, however, that although there are indeed a number of strong coincidences between the records that not all these data strands may be connected. Thus, the changes in settlement behaviours noted above may be as much to do with a greater shift towards regional and individual behaviours – perhaps a merging of new and old life-ways – and towards an admixture of mobile and settled existence, that may have more to do with changing social relationships as well as the realities of food production on a wet Atlantic island. The peak in passage tomb construction at this time certainly attests to changing social and ideological structures and the prominence of certain places in the landscape. Likewise, changes in the choices of food, or at least in the archaeological recovery of food remains, may in part relate to the practicalities of the new social relationships. Nevertheless, the numbers of records from across north-west Europe that emphasise environmental changes at this time suggest that communities may have modified aspects of behaviour in the light of climatic uncertainties and potential difficulties in crop production.

4.6. Late Neolithic (3100–2500 cal BC)

In view of the events occurring in the Middle Neolithic, it is clear that a closer examination of the Late Neolithic and Early Bronze Age are warranted. Our investigations did not set out to examine this period in any detail, being focused on the earlier stages of agriculture.

The start of the Late Neolithic comes at the end of a series of environmental events, including a narrow ring event in the Irish bog-oak record at 3190 BC, change in water tables in Scottish bogs, and in the geochemistry of ice cores due to alterations in ocean dynamics (Baillie, 1999; Moir et al. 2010) suggesting another period of cooling conditions. The main phase of deposition in passage tombs came to an end at or before 3000 cal BC (Brindley et al., 2005; Bayliss and O'Sullivan, 2013; Schulting et al., forthcoming). From this point in time, the archaeological record slowly begins to proliferate with signals of settlement, following the hiatus observed during the Middle Neolithic. Archaeological data for settlements during this period are biased to the north and east of Ireland. Many of these sites are associated with Grooved Ware pottery, which was introduced to Ireland from Britain at the start of the Late Neolithic period (Sheridan, 2004). Dating appears to be an issue as many of the radiocarbon dates are based on charcoal and several of these may actually relate to Bronze Age features. Archaeobotanically, very few of the sites examined date to this period, although there is some overlap between patterns in the data reported in the MN II and this period.

5. Conclusions

The new dating programme has contributed 187 AMS ^{14}C determinations relating to the Irish Neolithic, representing a major new corpus of material that has relevance not just to Ireland but to wider European Neolithic debates. The Bayesian analyses of existing ^{14}C dates and settlement data have allowed us to clarify the changing nature and sequence of Neolithic settlement at this time. We have been able to re-evaluate individual site chronologies and obtain a more nuanced view of the tempo of change. Alongside the archaeological work, we have created new palaeoecological chronologies using a standardised Bayesian methodology for existing dated Irish pollen sites. This has produced more robust and comparable records, with quantified uncertainties of the timings of key points of Neolithic vegetational change. In turn, this has allowed the palynological record to be related to the archaeological record more clearly than previously.

The results of our project are consistent with a rapid and abrupt transition to agriculture, particularly from c. 3750 cal BC, though this does not exclude an earlier Neolithic presence, hints of which are found at a number of sites. This complements the models of dispersal of the Neolithic across Britian and Ireland presented by Whittle et al. (2011). The nature of archaeological activity between the 'traditional' date for the start of the Neolithic, 4000 cal BC and 3750 cal BC, remain unclear due to chronological uncertainty and a lack of clarity as to the nature of settlement and agricultural activity – if any – at this time. The findings from Ferriter's Cove and Magheraboy remain unusual in this context and suggest further research is necessary to resolve chronological uncertainties (especially in the latter) and whether these sites are isolated examples. The dates from Poulnabrone are more robust, and precede the currently available evidence for cereals by up to a century (Schulting, submitted). What is clear is that the early phases of farming coincide with a boom in activity and expansion of settlement, with increases in the visibility of the archaeological record shown in cumulative ^{14}C data. However, these early phases were replaced by an apparent decline when activities become more ephemeral, with perhaps greater use of some wild resources. This is registered in the cumulative ^{14}C data, settlement, plant macrofossil and pollen records. There are other hints within the records, however, that our knowledge of the archaeological record of this period immediately after the start of agriculture, the Middle Neolithic, is particularly weak and needs further attention. Comparison with other palaeoenvironmental data, especially the bog-oak records and bog surface wetness curves, indicate the possible association between vegetational, environmental and archaeological change

during the period 3500–3000 cal BC and coincides with changes in archaeological and environmental records in England, Scotland and further afield. Of course, the links between the various records, causes and effects will require further investigation and may not necessarily describe simple one-to-one relationships. Indeed, they may imply resilience and adaptability in the face of a variety of social, ideological and environmental changes.

Archaeobotanical analyses have provided the first comprehensive overview of cereal crops and associated weeds deriving from Neolithic deposits in Ireland. This has revealed a wider range of taxa from a larger number of sites than previously known and, importantly, that agricultural practice was based on a system of permanent plots, probably akin to 'garden' agriculture. Such insights have important implications for our understanding of Neolithic agriculture, and strengthen the evidence for more intensive cultivation in northern and central Europe. Intensive cultivation associated with fixed-plot agriculture suggests Neolithic communities in Ireland were creating a sense of place not only in the construction of houses, but also in their engagement with the wider landscape and their investment in particular patches of land (cf. Bogaard and Jones, 2007, 367). Finally, the concept of intensive, fixed-plot agriculture across central and NW Neolithic Europe has important implications for other research areas such land clearance and the Holocene carbon cycle. This is because different assumptions of past land usage have profound impacts on how past carbon cycles are modelled. Shifting agriculture, for instance, has a significantly higher impact on modelled cumulative Holocene CO_2 emissions, compared with more permanent agriculture practices (Kaplan et al. 2010).

The importance of timing, above all, is stressed. If we wish to integrate archaeological and palaeoecological narratives, then much greater chronological control is required of both lines of evidence. Huge advances have been made in recent years in archaeological chronological precision, but the same progress is needed for palaeoecological data where applied to archaeological problems. The latter has tended to focus at centennial or millennial time-scales whereas archaeology is now discussing decadal scales. To meaningfully investigate human–environment interactions requires chronological control from the contributing datasets at a common scale, a scale that archaeology is dictating. This is achievable, but will require a change in 'mind set' in the palaeoecological community to place greater emphasis on improved dating strategies and a greater appreciation of precision and uncertainty.

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Appendix A. Supplementary data

A list of the new ^{14}C dates may be accessed via the Supplementary Data Table 1.

Supplementary Data Table 2 displays details of the pollen sites that were not used in the age-modelling.

An on-line simplified version of the archaeobotanical database can be accessed via our web site: http://www.chrono.qub.ac.uk/instar/archaeobotanicalDatabase.php.

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